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SURFACE PREPARATION AND COATINGS  
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MARINE INDUSTRY STANDARDS  
WELDING  
INDUSTRIAL ENGINEERING  
EDUCATION AND TRAINING

# **THE NATIONAL SHIPBUILDING RESEARCH PROGRAM**

## **Evaluation of Shipbuilding CAD/CAM Systems (Phase I)**

U.S. DEPARTMENT OF THE NAVY  
CARDEROCK DIVISION,  
NAVAL SURFACE WARFARE CENTER

in cooperation with  
National Steel and Shipbuilding Company  
San Diego, California

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NSRP 0476

Final Report

**EVALUATION OF SHIPBUILDING  
CAD/CAM SYSTEMS  
(PHASE I)**

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U.S. Navy

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A list of participants on the shipbuilding CAD/CAM/CIM evaluation project team is included in Appendix H. Likewise, the participants from the above organizations are also listed. The preparation and open discussion by these participants was instrumental to these evaluations.

## **1.0 EXECUTIVE SUMMARY**

Commercial shipbuilding orders have been increasing worldwide and, for certain product segments, are expected to experience continued strength, possibly for several decades. This follows a 10+ year period during which weak demand could not sustain the available capacity resulting in subsidized prices, voluntary production limits, and numerous shipyard consolidations and closings. With an eye to the more recent market expansion, new capacity is now being added, most notably in regions previously not participating in any significant shipbuilding. These regions tend to enjoy labor cost currency exchange rate, and modern facility advantages over the world's traditional shipbuilders in Europe and Japan.

The world's traditional leading commercial shipbuilders have not been idle. In efforts to compete profitably in today's shipbuilding markets characterized by over-capacity and extreme price pressures, these yards have developed various strategies to reduce shipbuilding costs and schedules significantly. The strategies include aggressive business practices, new or significantly enhanced computer technologies, factory automation, capital investments, and an unfaltering attention to process discipline and continuous process improvement. Computer-Aided Design (CAD) technology has been evolving in these shipyards since the 1970s. In the late 1980s and early 1990s this technology has been significantly enhanced through the addition of Computer-Aided Manufacturing (CAM) and factory automation, especially in cutting and welding. The 1990s is seeing the integration of these engineering and production technologies with planning and business systems. Truly Computer-Integrated Manufacturing (CIM) is emerging as one of the technologies of the 1990s by which world-class commercial shipbuilders plan to maintain or return to profitable competition in world markets.

This project's Phase 1 Assessments of shipyards and software developers provides both overview and depth into "world class" commercial shipbuilding operations. Shipyards in both Europe and Japan, which combined profitable operation and extensive use of computer technology in their operations, were initially studied. Later, specific assessments were conducted regarding use of commercially available CAD/CAM shipbuilding software in smaller or "2nd tier" shipyards.

All of the shipyards studied have some of the highest average labor rates and the lowest labor content per CGT (compensated gross ton). These yards were selected in order to provide the best information concerning possible direction for U.S. shipbuilders approach to new CAD/CAM/CIM systems to achieve even better results than those studied. Our assessments indicate that this performance is a result of aggressive business practices that:

- provide on-going market share and business backlog;
- continue profitable operation in spite of relentless price and schedule competition;

Ž use the best practices available related to people, processes, facilities and technology.

This report concentrates on the specifics of technology, but it is not possible to decouple technology from the other factors listed above. Specifically, we have observed that certain technologies - in particular CAD/CAM/CIM and accuracy control - are essential enabling ingredients in 1996 “world class” commercial shipbuilding. However, effective CAD/CAM/CIM and accuracy (i.e. elimination of variations) technologies are not the only deciding factors.

The assessed shipyards represent the survivors of significant industry reductions in both Japan and Europe. These shipyards have adopted strategies that produced improved business results primarily through continually reducing materials costs and labor content. Lower cost alternatives have also been developed, such as reliance on managed networks of suppliers and subcontractors for many components and services. Actual on-site shipyard work concentrates on only those tasks that the yard does best their “core competencies.” For example, in all shipyards, structural fabrication was a core competency.

A key factor in achieving essential business improvements appeared to be a clear identification and communication of the business goal and strategy to the work force. This process is “top-down:” driven with executive management actively supporting the initiatives with intensity over the full duration required for implementation. Just as importantly, the work force is directly involved in understanding the barriers and designing and implementing the process changes from the bottom up. The processes were observed to be handled in different ways in the different cultures. At Hitachi, each employee provides one or two suggestions per month that are all reviewed by management and over 50 percent are implemented. At Odense, all executives, production management, and union workers are involved with the approval of estimates and schedules for a new ship contract. During project execution, all are accountable for achieving the required contract performance.

The yards studied are in the range of 20-30 labor hours per CGT, with Odense quoting ten labor hours per ton of steel for structural work. Due to different strategies and core competencies, these figures are difficult to correlate with the specific work force information provided. However, the small number of total workers is consistent with the quoted productivity.

The following report is assembled as a descriptive overview of the information gleaned by the project team. Detail is omitted by necessity rather than choice. However, the detail has been considered by the team during Phase 2 of the project in developing the requirements for a world-class, future-oriented U.S. shipbuilding CAD/CAM/CIM system. Access to detailed information collected during the assessment visits is available through the individual team members.

## **2.0 BACKGROUND AND INTRODUCTION**

### **2.1 BACKGROUND**

This report is the Phase I final report of the National Shipbuilding Research Program (NSRP) project (Project Number 4-94-1) to evaluate world-class shipbuilders' existing CAD/CAM/CIM system implementations. Five U.S. shipyards participated in this study along with personnel from University of Michigan, Proteus Engineering, and Cybo Robots. Project participants have backgrounds in design, computer-aided design (CAD), manufacturing processes, computer-aided manufacturing (CAM), production planning, and computer-integrated manufacturing/management (CIM). The results of this evaluation provided the basis for the CAD/CAM/CIM Workshop presented in conjunction with the 1996 Ship Production Symposium, and will be used as background in Phase II of the project to develop requirements for future shipbuilding CAD/CAM/CIM systems.

Due in part to a heavy shipbuilding workload by the world-class European shipyards, only the Odense Steel Shipyard could undertake the evaluation in the depth desired by the project team. This shipyard utilizes systems built around the HICADEC product modeling software developed by Hitachi Zosen. Consequently, the project plan was revised to include reviews of two other world-class shipbuilding software systems during the European shipyard visit trip: TRIBON from Kockums Computer Systems and FORAN from Senermar. These reviews were helpful in better understanding differences in software systems and the effects these differences have in implementation strategies. These reviews will also be used in the second phase of the project, which calls for the development of requirements for future-oriented systems that can materially improve U.S. shipyard productivity and, as a result, competitiveness.

A contributing factor to the cooperation and openness exhibited by Odense in hosting the NSRP evaluation team is believed to be the value Odense places on NSRP research and reports. Torben Andersen, Exec. V-P and our principal host, stated that Odense has benefited over the years from this type of research and open reporting.

The "European Practice" descriptions in this report are primarily based on Odense Steel Shipyard practices. The tools used at Odense appear to be a "patchwork quilt" of tools and systems that have evolved at Odense over the last ten to twelve years. Some of the tools are "3rd party" software products while the majority are "home grown" applications designed to either integrate or interface with existing tools and/or databases. Clearly the CAD/CAM/CIM approaches taken in hull structure and outfitting are not identical. Noticeably missing from the overall Odense capability were effective cross-discipline associativity and topological product modeling. Noticeably abundant was the deployment of systems throughout the many functional areas of the shipyard and the

high degree of integration between CAD product models and other functional systems (e.g. purchasing, production planning) and automated robotic welding facilities.

The “Japanese Practice” descriptions in this report are based primarily on visits to Hitachi and Mitsubishi shipyards. These two visits provided details that confirmed many of the approaches initially observed at Odense. Both Japanese shipyards have developed their CAD/CAM/CIM approaches internally and have also implemented their own applications to reflect internal processes and practices. Both yards are now part of a national effort to utilize CAD/CAM/CIM as a major improvement tool in increasing shipbuilding productivity and reducing product cycle times.

Hitachi and Mitsubishi differ in their approach to product development, with Mitsubishi concentrating on small lots or even single ship product development while Hitachi focuses on medium lot size to long run product development. Both yards have significant facilities in which utilization is regulated as a national approach to stable ship prices. In this environment, the facilities have been downsized in total output by reducing the work force and the number of shifts worked. It appears that both yards have in the past, and could again, double or triple their output if market conditions allowed. The production processes and work force reflect constant improvement over thirty years and are considered the best available for assessment. Factory automation of steel cutting and assembly welding is very advanced and important in all shipyards’ current and future plans.

## 2.2 REPORT ORGANIZATION

Following the Executive Summary, this report is comprised of six main subject areas as follows:

- 1 Background and Introduction (Section 2.0)
- 1 Significant Findings (Section 3.0)
- Ž Shipyard Visit Reports (Sections 4.0 through 9.0)
- 1 Commercial CAD/CAM System Visit Reports (Sections 10.0 through 13.0)
- Ž Other Visit Reports (Sections 14.0 and 15.0)

Additional information, acquired or developed during the course of this project, has been included in appendices to this report. In addition to providing some of the details about the project methodology and specific survey responses, these appendices provide additional background material about shipyard practices that often relate to the individual shipyard implementations of CAD/CAM/CIM technology.

### 3.0 SIGNIFICANT FINDINGS

#### 3.1 SHIPBUILDING BUSINESS OBJECTIVES

The shipyards and other businesses assessed were selected in order to provide the best information concerning possible direction for U.S. shipbuilders' approach to new CAD/CAM/CIM systems to achieve even better results than those studied. Our assessments indicate that this performance is a result of aggressive business practices that:

- Ž provide on-going market share and business backlog;
- l continue profitable operation in spite of relentless price and schedule competition;
- l use the best practices available related to people, processes, facilities, and technology.

This report concentrates on specifics of technology. Specifically, we have observed that technology - in particular CAD/CAM/CIM technology - is an essential enabling ingredient in 1996 "world class" commercial shipbuilding. However, effective CAD/CAM/CIM technology is not the deciding factor.

To further understand this point, we have selected examples of the business practices that are considered significant in achieving and sustaining a competitive commercial shipbuilding or industrial capability. These examples will be further expanded in the Phase 2 requirements report. Examples of business practices include:

New product development

Customization of current products

Reduced customer/supplier/subcontractor risk

Sufficient workload for full & consistent use of core resources

Reduced cost and contract cycle

Reduced cost through

Ž Core competencies (project design/purchasing/procurement/execution; hull assembly & erection; pipe fabrication hull & tank coatings; outfitting machinery modules)

Ž Variance elimination (product & schedule/activities)

Ž Humanware

Ž Quality assurance by/at worker levels

Ž Design standards and process standards

l Minimal-to-no customer involvement in internal processes (either business or production)

Reduced contract cycle through:

Ž Elimination of design, procurement, and production engineering errors/omissions

- Ž Early project schedule simulation
- Ž Effective problem/crisis resolution

Many of the practices relate to processes that are essential to shipbuilding and have been improved incrementally over long periods. Others are more revolutionary and are based on continually questioning the business opportunities with customers and suppliers given changes in underlying constraints. The most effective practices appear to be based on very subtle differences in core corporate understanding and attitudes toward the business environment. This business environment is a complete system including employees, customers, suppliers, facilities, products, processes, and communications. CAD/CAM/CIM technology implementation was observed to provide a critical tool to leverage subtle differences in approach to commanding differences in performance. Other approaches rely on differences in the way people use CAD/CAM/CIM technologies to improve performance and productivity. This can be referred to as “humanware” or the involvement of people in the use of technologies. “Humanware” practices provide the sustaining core of knowledge and capability to which automation can bring intense leverage for improvement. Effective automation without “humanware” was not observed in any of the companies assessed.

### 3.2 TECHNOLOGY ALIGNMENT

A major finding relates to the reasons behind use of technology. As previously stated, the companies assessed had adopted aggressive business practices. Further, the use of technology was not pursued for its own sake, but as an enabler to achieve the business objective. Business objectives of the assessed companies had been effectively transformed into implementation plans and projects leading to new or modified processes. People in the organizations brought about both the vision for the improved business practice and the implementation approach.

As with many new approaches or improved processes, certain portions were copied from previous successful implementors in a related approach requiring constant benchmarking of competitor’s processes. However, many of the examples above required significant basic research and development before feasibility could be determined as no direct implementation of the approach was available. It appears that careful understanding of the needed, desired, or possible business improvement is a fundamental part of technology considerations.

The cost, time, and resource commitment for technology could not come without management understanding and involvement in the envisioning and planning processes. Feasibility and eventual full implementation is integrated with national or community funded and shared efforts, such as the European Community R&D robot projects or the Japanese Ship & Ocean Foundation funded CIM development. Also, intimate process

knowledge is needed of the existing processes to understand the barriers to business objectives and the potential paths around the barriers. The real secret is to determine the bottlenecks in the processes or barriers in business practice that control or limit profit. That understanding can equip management to lead or direct changes in the most effective course.

Phase 1 will develop a tighter link between specific business cases and the CAD/CAM/CIM technical requirements. The clear message from the assessed companies is that investment in technology is appropriate if it has a clear path to improved business results that create added profits. Other activities, which do not meet this test, are eventually dropped. The challenge is to do the envisioning and analysis of what is most probable to reach the result, and not to simply pursue the newest technology without considering the potential return.

### 3.3 IMPLEMENTATION STRATEGIES

We have sought to document the observed strategies as Significant Findings and to identify the factors that seem most important to their success. The shipbuilding examples are divided into several areas of activity. These include:

- Ž independent benchmarking and product/process analysis
- l independent process implementation
- l cooperative research & development
- Ž partnering implementation

The strategies, which seem the most relevant to current U.S. shipbuilding requirements, combine both the business objectives analysis approach and the implementation activities above. These include:

- Ž concentration on “core competencies;” i.e. Doing what you do best and finding partners, who are also “best,” to do the rest. Example - Odense core competencies in Design/Production/Project coordination, structural work through ship completion, steel pipe fabrication, assembly of major outfit t modules, and unit-level application of coatings.
- Ž elimination of variations in performance leading to improved through-put and accompanying improvement in productivity. Most significant examples include:
  - l structural part and assembly dimensions
  - Ž duration of planned work operations
  - l supplier and subcontractor delivery and quality
  - Ž workers responsible for quality and schedule with minimum support and no inspection

- Ž use of Product Model data and highly integrated applications to:
  - Ž eliminate errors and omissions in design products
  - Ž reduce risk in early estimating and scheduling of labor, material, and facilities
  - Ž provide effective information for factory automation using robotics at no increase of touch labor or engineering schedule. Robots used in steel cutting/marking, welding, and painting
  - Ž increase product reliability and performance through sophisticated analysis
  - Ž use of their people as the major part of systematic improvements to performance and flexibility. Example - Japanese all speak of “humanware” in the same manner as “software and hardware” in system development and implementation.
- ŽŽ Ž involvement in continuing research and development through partnerships with both competitors and nonmarine industry groups. Examples: Japanese shipyards in S & O Foundation CIM project, and Odense in EC projects related to robot welding programming and control.

All assessed companies performed benchmarking and product/process analysis as routine functions. These were effectively communicated although not through a formal or standardized methodology. All companies were involved in both cooperative R&D efforts and partnering for implementation of products and processes. The partnering and cooperative efforts used varied and flexible groupings of needed experience. The relations formed could be long term ( i.e. Odense and Hitachi in development of HICADEC ) or short term ( i.e. the 30-40 robot projects followed by Odense in developing its new controller approach). However, the most important observation is that the companies were responsible for implementation and applied the technology to targeted processes. This allows the subtle differences of facilities and humanware to be considered and to form the sustaining knowledge and ownership of the process needed to be successful. Eventual confirmation of attaining the desired business objective has to be measured and, if necessary, refined. Refinement brings in the concept of continuous improvement and setting new business objectives ( i.e. Odense implementation of block welding robots led to the decision/need to reduce part dimensional variance).

To further illustrate this environment, Odense provided two stories, both involving the Chairman of AP Moeller Group ( the owner of Odense ), Mr. Moeller. In about 1980, Mr. Moeller was aware of the growing price delta in ships constructed in Asia versus Europe. He had a short meeting with the shipyard management and simply asked them to develop and implement an approach in which he could continue to afford to build some of his ships at Odense. The result was a plan leading to current capabilities. Previous organizational conflicts were put aside in the effort to achieve the larger and more important goal. **The** second is on-going. Mr. Andersen, as Yard General Manager and new Partner in AP. Moeller, is frequently asked about the progress of process improvement projects, especially those using high technology solutions or cutting edge development. The pressure is always to initiate additional projects.

### 3.4 CAPABILITIES AND OPERATIONS

Most shipyards looked remarkably similar. The copying effect with continuing benchmarking and procurement of equipment from a small set of suppliers leads to the similarity of look. The differences are subtle as to why a particular yard has different performance. The primary reasons for different performance have been stated above. Specifics of each individual company is part of the specific company report.

In general, all shipbuilders were effective in steel production. The shipyards and Black & Veatch (B&V) were also effective in design/production/procurement/project coordination. However, the most significant strength was in the leadership needed to assess the business objectives and translate those objectives into tactical plans for development and implementation of product and process changes. These changes kept the leading companies ahead of their competitors.

### 3.5 APPLICATION COMMONALTIES

Software and hardware applications observed have commonalties as they relate to specific processes. That is, where processes in the shipyards are identical, then applications have similar functions. The manner of interaction and the style of operation again relate to the particular approach in place in the shipyard.

The three primary yards assessed and B&V all use home developed applications built on external core technology. The investment in knowledge base explains the largest part of the company's success in use of CAD/CAM/CIM. The effort needed to understand how the applications relate to the process provides a very strong basis for use and improvement of the applications and the processes. The observations at Howaldtswerke-Deutsche Werft (HDW) (and NIS & SMK, as support integrators for HDW) indicate that use of third party applications, such as TRIBON, can be effective with appropriate support resources. KCS has stated that Japanese shipyards using TRIBON have made large investment in understanding and using the system, even including significant enhancements, prior to the decision to fully implement.

An example of differing philosophies affecting application styles is the Odense development of a planning and off-line programming application - PROMOS, and Hitachi performing the same functions using PHI directly. Hitachi had decided that automation was very important and needed to develop an "intelligent planning" application to implement early stage detailed estimating. The applications at the base level were HICADEC; the implementation was specific to the direction needed to implement the business objectives.

### 3.6 UNIQUE IMPLEMENTATIONS

Unique implementations of CAD/CAM/CIM technology were found at Hitachi, Mitsubishi, and B&V. In each case the uniqueness of the application approach was a reflection of the specific need of that business on the applications.

Hitachi had developed a support approach for basic design to improve information access in the tendering stage. This was combined with the intelligent planning application from the PHI database using 250 rules to plan the ship blocks and routing, as well as the preliminary labor and task durations. Combined, these applications provided a significant preliminary design capability to ensure accurate cost and schedule prediction with little time or labor needed.

Mitsubishi had developed a complete design and design analysis set of applications to support its direction to compete for one-off product development. The DAVID and MATES applications were developed to provide for copying of design intent in structures to detail level from the hull lines and midship section. Analysis was integrated to assure initial consideration of powering, fatigue, loading, and operations, which were of particular interest to the owner and not normally considered until later in the design process.

B&V had arranged its entire system around data-centric and computer-automated application concepts. Taken together, these two concepts provided all data to all potential participants in a project all of the time -24 hours a day world-wide, and the ability to change/correct the project with minimal delay and disruption normally associated with CAD/CAM approached. The data are in the most abstract form common to the process (i.e. similar to the desired form of NIDDESC/STEP AP descriptions), and processes are automated to work on the data using standards to produce the final output of the process with minimum labor. As with other examples, B&V is directing development of these application approach based on business objectives.

## **4.0 ODENSE STEEL SHIPYARD**

### **4.1 ODENSE SHIPYARD OVERVIEW**

Odense Steel Shipyard Ltd. was founded in 1917 and consisted of a 40,000 DWT capacity yard in Odense, Denmark. In 1957-1959, new facilities were constructed in Munkebo, just north of Odense. This yard was designed for 200,000 DWT maximum ship size in two parallel construction halls and drydocks. The first vessels built at the Munkebo yard were 50,000 DWT product tankers for Chevron. In 1969, construction began on a new building/crane/drydock complex for 1,000,000 DWT vessels. Steel fabrication capacity at the current shipyard is about 250,000 tons/year. Current production is about 180,000 tons.

Current work underway at the yard during the NSRP team visit was transitioning from a six vessel 293,000 DWT VLCC to a nine vessel 4800 TEU container ship. A Maersk Line 1500 TEU container vessel (the TRSL ARCTURUS) arrived dockside during the visit to begin a major overhaul of its slow-speed diesel main engine. The VLCCs are priced at 750M Danish Krona (approximately \$130M) and are currently being produced in the 1,000,000 DWT facilities at a rate of three to four ships/year. We were told that the VLCCs are being produced at ten to twelve man-hours/ton. According to Torben Anderson (Executive Vice President at Odense), the original 200,000 DWT facilities are believed to be capable of somewhat less than 20 man-hours/ton.

The shipyard is part of the Odense-Lindo organization, which is part of the A.P. Moller Group. Odense-Lindo is primarily a container shipping company. Odense-Lindo includes Maersk shipping and container manufacturing, Loksa Shipyard (Estonia), and Robitec as well as the Odense Steel Shipyard. Employment is about 4,000 in Odense-Lindo, of which 3,000 are at the Munkebo Shipyard (500 white collar). The Planning/EDP/ Automation department consists of about 40 people with about half of these people in the Robotics Automation/Projects/Sales group. In addition, about 22 people from Maersk Data (another A.P. Moller Group organization) are resident at Odense supporting the information systems (hardware and software) used at the Odense shipyard. Systems requirements and specifications are developed by the shipyard users and the software development is done by Maersk Data personnel. A “help desk” system is supported with an internally developed work/problem tracking system. An annual contract is awarded to Maersk Data for these support services, which also includes sub-contracts to Data General for on-site (2 full-time employees) hardware maintenance on all computer hardware.

A newbuilding project is considered to have three phases; design, engineering, and construction. The design phase appears to be comparable to the concept, preliminary, and contract design phases typical of U.S. practice. The engineering phase appears to be comparable to the detailed design phase. Functional performance issues are addressed in both the design and engineering phases with naval architecture issues being the primary focus in the design phase. Marine engineering issues (e.g. heat balances, pipe system pressures and flow, electrical system performance, pipe thermal stress, etc.) are addressed in the engineering phase.

The current shipbuilding facilities consist of the two parallel 220,000 DWT vessel production lines built in 1957-1958 and the 1,100,000 DWT line built in 1969-1970. These facilities are very clean, well organized and laid out for efficient material handling. The facilities include 400 ton and 1,000 ton cranes. Most of the newbuilding work is done in the 1,100,000 DWT facilities. The end portion of the large drydock nearest the main construction hall has been partitioned from the remainder of the drydock and is currently used for assembly of large midbody sections. Some offshore work has been done recently in the 220,000 DWT line,s but they are generally used for storage and steel work on blocks not suited for the more automated facilities. A sketch of the site facilities is included as Figure 4.1 and an aerial view is provided in Figure 4.2. The aerial view shows a small portion of the 1,100,000 DWT drydock and 1,000 ton crane in the foreground. The original 220,000 DWT drydocks, cranes, berthing dock, and construction halls appear in the background.

The labor force is union organized, with a clear feeling that certain tasks are inappropriate for Danish labor. Despite considerable on-going work to complete the last VLCC and the first 4800 TEU vessel, the yard appeared to have relatively few production workers moving around compared with U.S. shipyards. The workforce did not appear to be abundant, suggesting an extraordinary efficiency in the shipbuilding process.

Design areas (structure and outfitting) are open (no partitions), very clean, free of clutter, and professional in appearance. Workstations are prevalent throughout these areas. Most workstations have the extensive symbol tablets utilized in the CAD systems of the early 1980s. For outfitting, these tablets were claimed to be more efficient than the pull-down menus provided by most modern CAD systems. The outfitting design office provides working space and CAD terminals for 10-12 engineers and 28 designers. About one to two weeks of formal training and two to three months of on-the-job experience is required to train the designers.

The contract award schedule for newbuildings is 5 percent at contract award, 5 percent at start of fabrication, 10 percent at launch, and 80 percent upon delivery. The breakdown of newbuilding costs was characterized as follows:

15-20% Direct Labor

20% Overheads and other costs including energy, maintenance, EDP, etc.

57-65% Materials and subcontractors

The design process is typically planned for a ten-month duration after which production is started. The rough breakdown of design tasks during this period is as follows:

Ž Contract award

Ž Phase I - Structure Definition and Design

Setup HICADEC project files (month 1)

Preliminary fairing (month 1)

Setup project standards (month 1)

Setup design sketches (months 1-3)

Shell definition (months 1-3)

Internal structure definition (months 1-6)

Final fit (months 5-6)

Design drawings (months 5-7)

Phase II - Production Definition and Design

Database separation (month 5)

Order steel (months 7-8)

1 Production start

Upper level management appears to have considerable involvement with operational problems, and research and development efforts. Each morning the production area managers walk through their areas checking status and problems. They then meet with their VPS, who, in turn, meet with the President and Executive VPS to resolve any outstanding issues affecting operations. In this manner, senior management is kept abreast of all production status and problems.

## 4.2 BUSINESS STRATEGY

The business strategy appears to have a long range focus, with emphasis on the large vessel product segment, in which Odense's facilities and automation technologies can develop and maintain steel fabrication competitiveness for current and future vessel contracts. The large vessel segment includes double hull VLCCS (300,000 dwt class) and large container ships (4800+TEU class). Repair work is done for Maersk at the request of the parent company. This kind of work, however, is not consistent with the "steel and piping factory" business used for newbuildings and is not sought. The split between in-house work and vendors' work seems to be driven by the "do what we do best" philosophy. Make versus buy decisions are continually being reviewed. With the

opening up of the low-labor-rate, Eastern European countries, new subcontracting opportunities are being explored to further Odense Shipyard's competitiveness. For example, a yard in Estonia has been acquired that is currently being used to manufacture small hatch covers. Other uses of these facilities are being investigated.

The management strategy is focused on continuous improvement. The goal is to continue to improve processes, personnel, and facilities so they become increasingly more efficient. Significant capital investments are made each year, justified by cost savings over multiship building contracts. Since the end of 1994, Odense has added a 12-robot flat block welding assembly facility, a two-robot curved block assembly welding facility, and anew plasma cutting machine with inkjet marking. The yard is in the process of building anew blast and coating building.

Odense invests in personnel resources, as well. The best example is the development of people who are now pushing the envelope of robotic and other forms of welding automation. Likewise, the shipyard has developed personnel who continue to develop and integrate a collection of CAD/CAM/CIM programs into effective systems. These systems include integrated product modeling and production management functionality devised by Odense personnel supported by Maersk Data network and software experts.

The typical award schedule is as follows; 5 percent at contract award, 5 percent at start of fabrication, 10 percent at launch, and 80 percent at delivery for a total of about \$150M per ship.

#### 4.3 COMPETITIVE STRATEGIES

The shipbuilding strategies focus on lowest cost, shortest production time approaches. Material costs have been determined to be the number one driver for productivity improvements. These costs have several elements; raw costs of materials, carrying costs (interest on funds tied up in materials), and "work in progress" (WIP) carrying costs on material and labor used to produce WIP inventory. Labor manhours was not mentioned as a driver for productivity improvement developments. Several elements of the Odense competitive strategies include:

##### **Ž Facility rationalization**

The Odense shipbuilding facilities are configured to produce large ships in a production line manner. The focus is on minimizing design time, minimizing construction time, and minimizing materials, and work-in-progress inventory. Internal analyses by Odense showed that when a six-month reduction in the time inventory is carried this resulted in a savings in the millions of dollars range.

## **Ž Do what we do best (subcontract what others do best)**

The Odense yard strengths appear to be steel and pipe fabrication, combined with heavy-lift (400 and 1,000 ton) cranes capable of handling large subassemblies and modules. Most other work (e.g. electrical, joining, pipe surface prep and coatings, HVAC, etc.) is subcontracted. As described in Purchasing and Vendor Relationships (Section 4.9), a network of suppliers is cultivated and monitored for performance. Pre-package units from specialized vendors (e.g. complete head/shower units) are utilized extensively to facilitate final outfitting. Most of the installation work, including joining and HVAC, is completed by Odense. Notable exceptions are electrical/instrumentation (vendor installed) and final interior ballast and tank painting (work deemed unfit for Danish workers).

## **Ž High level of planning and control**

The production planning is done in four levels with the managing director authorizing the overall “A-Planning; construction schedule” level. This entails only about five key dates for each ship in the series and covers a 2-4 year timeframe. This planning addresses overall shipyard resources including necessary skills and education, and allocation of contracts to subcontractors. “B-Planning” by production management determines the modular breakdown, required resource schedules, and overall schedule of activity flow needed to achieve the construction schedule. This planning addresses a 6-12 month time frame and constitutes the primary basis for monitoring construction status. The “C-Planning” addresses individual production area workloads over the upcoming 12-week period. This planning is updated weekly. Within these periods, each production department does “D-Planning” of the first 4 weeks’ work plans for efficient use of resources in meeting the “C-Planning” production schedules. For example, pipe bend tooling is scheduled based on meeting current and, to the extent practical, upcoming production needs for a specific pipe size, rather than changing after meeting only the current needs for that pipe size. Rules-based programming is used to automate much of the estimating and job routing through shops.

## **Ž Just in time procurement and production (pull scheduling)**

Within the parameters discussed above, materials and finished subassembly components needed to support production schedules are procured (from vendors) and produced (at the shipyard) according to the upcoming needs outlined in production schedules. Arrangements with suppliers call for frequent materials restocking with minimal warehousing of stock on-site. Material requirements are prepared and communicated to each vendor by production planning to facilitate their restocking. Each department schedules its work based on needs to support the next eight to twelve weeks of production. Short term (four week) work plans in the various production areas are similarly scheduled.

## **Ž Automation and High tolerance manufacturing**

Very stringent dimensional tolerances (e.g. within  $\pm$ mm for profile cutouts) and significant emphasis on dimensional control was evident in every stage of fabrication. “Neat” construction (i.e. cut to size with no excess to be cut-to-fit later) is emphasized along with good fit-up at welded joints with a minimum of filler pieces. The good joint fit-up is essential to robotic welding, which, in turn, produces good weld quality with a minimum of rework. Likewise, use of collars is minimized by use of tight fitting cutouts around stiffener penetrations. Discipline and adherence to standards is also evident throughout the organization, which helps maximize efficiency through repetition. Most automation and standards seemed to emphasize simplicity for the operators and workmen.

Odense’s future vision is to automate as much welding as possible. A key benefit is a major reduction in training time; that is, the time to train a skilled welder versus the time required to train a computer operator to program the welding.

## **Ž Quality Assurance**

Quality control functions were disbanded early in the Odense automation effort. The responsibility for quality is with the line organizations, including labor. Dimensional data are collected by the production workforce and used to make corrections as needed. Periodic audits are performed by a two person Quality Assurance Department. The emphasis appears to be in fixing the process rather than in checking the output.

## **Ž Performance-based labor compensation**

Under the wage agreement with the union labor, a bonus system is employed, which compensates labor for production as well as time spent on the job. Production planners set the rates or value for defined production tasks. While the exact method was not fully explained, it appears that 90 percent of labor’s agreed compensation is paid based on hours worked. The remaining 10 percent is pooled and redistributed weekly or monthly based on actual work group production versus these set rates or values. It was pointed out that some elements of the labor force more aggressively pursue these bonus payments than others, with outfitters said to be earning up to \$1 .00/hour more than their counterparts in steel fabrication. It was clearly stated that a production task is complete only when it meets correctness and accuracy standards. Any rework required to complete a task must be absorbed by production labor and affects their competing for bonus payments. This appears to be a key element in the quality assurance program. The system sounds quite complicated; claims can be made by labor for lost production time due to unavailability of needed materials or for equipment maintenance. Overall, however, the unionized labor force generates a sense of ownership for productivity at the group (i.e. work crew) level.

## **Ž Push production planning as far forward design process as practical**

Figure 4.3 illustrates the Odense thinking in terms of production planning. The decisions made early in the design process (before construction begins) have the greatest effect on total production costs. Consequently, the emphasis in much of the current Odense development work is to push production considerations well forward into the design and engineering phases of a newbuilding project. This emphasis is evident in the use of automation tools to help reconcile ship systems PIDs with the build strategy and compile material and resource requirements very early in the design phase. It is also evident in the use of welding cost estimation algorithms during engineering (i.e. detailed) design. Furthering capabilities in this area seems to be a focus for Odense's 5-year development plan.

### **4.4 AUTOMATION**

#### **4.4.1 Background**

Odense started to utilize NC data from the Steerbear system for plate cutting in the mid-1960s. From 1971 through 1982, Odense utilized the Steerbear CAD software, which is now part of the TRIBON system from KCS. Concern over Kockums closing of their Malmo shipyard and difficulties with interfacing and getting software enhancements implemented in a timely fashion caused Odense to transition from Steerbear to an in-house system development in 1982. In 1983, a serious automation effort began with Supermini computers, CAD/CAM software, and automation of cutting and welding integrated with the CAD/CAM. This effort was concurrent with the introduction of "neat" construction methods with dimensional tolerances reduced from 2-3 mm to 1 mm for double-hulled VLCC vessels. The original objective of the automation effort was to reduce material costs, primarily reducing inventory costs, as illustrated in Figure 4.4.

HICADEC was selected as the basic 3-D modeling system for the automation development and is still a key element of the Odense capabilities. While AUTOKON was evaluated and deemed to be impressive, Odense was hesitant to source this software from a software company without shipyard connections. In 1982, Odense bought the FORAN general design (Naval Architecture calculations) package, which was used until about two years ago when NAPA software was acquired. An agreement was made with Hitachi Zosen in which Hitachi and Odense direct the HICADEC development efforts and Hitachi does the software development. Odense does considerable in-house development work on integration tools between HICADEC and other automation systems (e.g. purchasing, material control, robotics, etc.) used at Odense.

Current hardware utilize UNIX in client-server arrangements. The entire shipyard site is connected with a 100 MB/sec fiber optic LAN ring providing redundant communication paths to minimize outage effects. Some 700-800 nodes are connected to this LAN including 140 assorted UNIX workstations (actually a mixture of workstations, X-terminals, and PCs with X-Windows emulation). The UNIX server workstations (primarily Data General) are centrally located and provide 140 GBytes of mass storage capacity. Electronic communications with Odense-Lindo headquarters in Copenhagen are linked through this LAN. Future plans are to move to supercomputing with massively parallel processing to simulate manufacturing processes as well as design. The computer hardware chronology and future directions were described as follows:

- 1975- mainframe computing
- 1985- super mini computers
- 1995- client/server systems (UNIX)
- 2005- massively parallel processors

#### 4.4.2 Implementation Philosophy

Automation direction is top-down driven. The philosophy seems to be that improvement projects must be undertaken to ensure future business and that current margins must be divided between profits and ongoing process technology developments to ensure competitiveness for future business. The management horizon must be decades, not years. Torben Andersen described the automation of Odense as a direction that, once begun, has no turning back. It involves capital investment, which is continual and extensive. Once begun, it appears that these investments build upon themselves.

While the automation direction is top-down driven, the specific programs and implementation design is mostly bottom-up. The importance of initiating process improvement technology projects in response to line organization requests was strongly stressed. While this development process is perceived (by senior management) to be slower and less seamless, these problems are considered of secondary importance compared to problems with selling R&D initiated projects to line organizations.

Automation and robotics projects are justified on series newbuildings projects; the newest 12-head robotics block assembly welding station was said to cost \$3.0M and is expected to have a two to three ship payback period on the current nine vessel 4800 TEU container ship order. This \$3.0M cost is assumed to be the incremental equipment and facility costs to adapt the robotics used for the previous VLCC robotics to the container vessel robotics facilities. Much of the development work underlying this and other product model-based automated manufacturing processes was undoubtedly done on cost-shared European Community (EC) research programs (see Section 4.8).

#### 4.4.3 Welding Robotics

The Odense Steel Shipyard has aggressively pursued robotic welding for enhancing production since 1987. It was suggested that optical camera sensors are preferable to laser sensors because of their small size. Stereo imaging dimensional feedback methods are being explored. The ROB-IN software developed by Odense is fully implemented and judged effective for flat plate assemblies. This approach is based on simple line and arc descriptions of the weld line paths. The “AMROSE” technology, based on NURBS mathematical descriptions, is in initial (prototype) implementation for curved plate assemblies and is still considered somewhat developmental. Technomatix ROBCAD and Deneb IGRIP software were evaluated for the curved plate programming task, but were considered to be too mathematically intensive for efficient off-line programming. The assembly support fixturing in their curved panel welding cell incorporates a tilt axis to keep the welding position flat. “SMART WELDER” technology for outfitting (pipe sections) is still in the research stage, supported by several European Community (EC) joint research projects (see Section 4.8).

The primary benefits from the use of robotics technology were described as improved weld quality and heightened attention to planning and quality issues. Tight tolerances are required for robotic welding, thus permeating strict attention to dimensional control throughout all fabrication processes. Welding productivity benefits were presented as marginal, mostly related to planning work such that process tasks are simpler and working conditions are better for individuals. The timely and accurate reporting of actual welding completed was suggested to be of more value than welding productivity enhancements. Similarly, the attention to dimensional accuracy at every stage of construction in support of effective robotic welding was described as one of the major benefits. The discipline applied to achieving this accuracy made significant process improvement occur in all operations, thus reducing costs and span times throughout the shipyard.

The accuracy approach to robotic welding explains Odense’s philosophy regarding sensor-based adaptive robotics. The U.S. is pursuing sensor-based adaptive process control as a means to overcome a degree of assembly inaccuracy that it believes cannot be avoided. The approach is to allow assemblies to have variances in position and fitup, utilizing adaptive control automation technology to sense and correct for these variations. This is in sharp contrast to the Odense position that production based on highly accurate assemblies is inherently more effective in terms of costs and schedules.

The robotic welding technology and systems developed by Odense are commercially available. Currently, installations other than at Odense are being used in Norway, France, Korea (2), and Denmark.

## 4.5 MAJOR CAD/CAM SYSTEMS

Odense began its automation effort in 1983 with the use of Steerbear. It later used HICADEC and GRADE/G, a graphic system developed by Hitachi Zosen similar to IBM's CATIA software. It appears that these systems provided 3-D product modeling tools and a somewhat open database architecture. Integration with manufacturing, planning, and management systems was not particularly well addressed by these CAD tools. This section describes some of these and other key CAD/CAM tools that have been subsequently integrated into Odense systems. Section 4.6 describes similar planning and control systems, and Section 4.7 describes some of the integration methods and tools.

The central computer room is housed in a building adjacent to the design offices. This facility has five Data General UNIX servers. One of the servers is an Ingress RDBMS server. It appears that Ingress is their database of choice for client/server applications. Ingress and HICADEC databases are stored on Data General CLAMON disk arrays filled with 1.2 and 2.0 GB disk drives - a total capacity of 140 GigaBytes. The local area site network utilizes a 10MB/sec Ethernet and a variety of networking hardware, specifically including Cabletron MAUs. The network is being upgraded with a 100MI3 fiber FDDI.

### 4.5.1 Computer-Aided Engineering, Design and Manufacturing

GRADE/G is primarily a computer-aided drafting system, which has been interfaced with the HICADEC 3-D product modeling system. It is used for stand-alone 2-D drawings. It also provides much of the capabilities to produce drawings based on extraction of the 3-D product model data. It was described as having been developed by Hitachi Zosen about 10 years ago and being similar to the IBM CATIA system. It is tablet menu driven.

HICADEC is the primary 3-D modeling system utilized at Odense. HICADEC-H is used for hull structure modeling and HICADEC-P is used for outfitting. The software was developed and is maintained by Hitachi Zosen for Hitachi, Odense, and one other shipyard. A brief description of this system is included in Section 13.0.

#### 4.5.1.1 Hull Structure

The HICADEC-H system was demonstrated for building a tank top assembly from scratch in an inner bottom unit. A batch program (BMTHIC, developed by BMT for Odense) is used from a X-terminal to transfer the hull surface information from HullSurf into HICADEC. An element drawing was produced by the designer for this block of structure. This drawing was really a view of the structural model similar to a scene in the AUTOKON module AUTODEF.

The first step in creating an element drawing involved setting boundary view limits (x,y,z) and a scale (for plotting purposes). A frame (X-Dist) table was accomplished during the BLINES conversion with BMTHIC. Planar surfaces are created by specifying x-y, y-z, or x-z coordinates in a manner very similar to AUTOKON. The tank top surface was created. The surface cut an intersection line with the shell. Transverse frames are automatically named with random numbers, which can then be overridden with specific names. A large tablet was used as an input device almost exclusively for all demonstrations. The tablet overlay was filled with small cells containing macros and commands.

Odense uses a manual penetration list prepared by the outfit designer to communicate piping penetrations to the structural designer. As HICADEC-H and HICADEC-P are not integrated, the list is manually updated if an outfit designer moves a pipe and changes the shape and/or location of a penetration hole. Stiffener cutouts are defined for the ship in a standard library. The library is copied from ship to ship and modified as necessary. The cutouts are parametrically defined, that is, automatically sized to the stiffener dimension and type.

The HICADEC-H modules appeared very similar to the AUTOKON AUTODEF module for defining structural parts. A point to be noted, however, is that graphically the user is defining the 3-D structural model by working in 2-D views. The user can work interactively in the standard plan, elevation, and section views. The database stores structural data three dimensionally, but HICADEC does not have the visualization software to provide 3D graphics in the expected sense. There is a capability to produce an isometric drawing with hidden line removal, but it is just a 2D drawing representation - it cannot be rotated, scaled, etc.

The hull structural is topologically defined, that is, if the tank top is moved up six inches, the floors and longitudinal girders will stretch. In another example, if a longitudinal girder is moved, the longitudinal stiffeners will move with it through the surface association. If the tank top was moved, all the associated parts and surfaces are automatically modified to compensate. The movement of parts and surfaces, as well as move manipulations, can be done either interactively or in batch mode. The typical designer prefers to do modifications involving large numbers of parts in batch mode.

The HICADEC-H Block System is used to assign assembly information to parts. It basically creates an assembly network with information from C level planners (see Appendix B) in the structural design area using PROduct Model System (PROMOS), a software application developed by Odense. The planning information is given to a HICADEC-H designer by a file. The designer begins by assigning a plate to a block. The stiffeners on the plate automatically become part of the block (a "loose fit" stiffener can be taken off and assigned its own block identifier at any time). The second phase of the structural design process involves the generation of plates parts and stiffeners. Weld

shrinkage is accounted for in some manner. Other production information is added in HICADEC. The system automatically creates a shape sketch drawing for each stiffener. TM is accomplished with a batch command. Odense's preference is usually for one stiffener per page, although the system can put multiple stiffeners on a single drawing. Simple stiffeners, those without cutout features like drain holes, are represented at four stiffeners/page. The typical stiffener, those with features such as cutouts, endcuts, or bending information, are done at one per page. The sketches are fully dimensioned, including bending information as appropriate. These sketches stay in design office for reference use only - they do not go to the shop. The only exception is for very few stiffeners that are cut manually.

The HICADEC-H Nesting function was demonstrated. Apparently only two of the 50 workstations are used for the nesting function. A different tablet overlay with commands and functions specifically suited for this module was used. The nesting process is broken down into three functions; ordering plate (size, thickness, and material grade), generation of N/C instruction sequence (e.g. hole lead-in parameters, etc., make cutting plan), and the creation of the nest layout drawing for the shop. The drawing itself will be eliminated as all of the burning machines are upgraded to full scale ink jet capability.

#### 4.5.1.2 Outfitting

Several features of the HICADEC-P outfitting system were highlighted as follows

- I Flange rotation calculations are performed in HICADEC-P for "post bending" condition. The flange welding machine operator will manually rotate a defined number of degrees before flange welding, so that the post bending operation alignment of the flange will mate with the adjoining piece.
- Ž The system is capable of doing on-line pipe run checks for producibility (flange location and bend parameters). Odense practice, however, is to execute overnight batch runs that produce lists of problem pieces.
- Ž There are unique piece numbers assigned to all pipe pieces. For revisions, a letter designation (e.g. A,B,C ) is added to establish a unique identifier from an old piece number.
- Ž A click on a piece in the product model (PROMOS) provides the production status information. The capability was lost in the last PROMOS upgrade, but it is supposed to be fixed. Future upgrades will also incorporate bar-coding for input of the data.
- Ž In the production system MAPSOS, the production flow of pipe is automated based on the type of piece. It appeared that product model attributes are defined in design and then some rule-based program is invoked to determine the pipe piece routing.

- Spring back calculations are not used (they are available in the HICADEC system). Odense practice is to depend on operators' experience because of too much variation in actual material properties.
- Pipe installation drawings are not system drawings with structural backgrounds. These drawings are isometrics, typically of several pipe pieces. Installation dimensions are to ship reference lines.
- Pipe shop production information is generated for one entire week of work and then nested by pipe size.
- Valves are defined as both stock and unique types. Both types have different procurement, tracking, and delivery rules.
- On pipe diagrams, the systems are highlighted and have dashed lines to represent block installation vs. on-ship installation.  
For advanced ordering, the system will provide quantities of the diagram components/equipment materials with the scheduling of material deliveries determined manually based on available information from the planning department.

#### 4.5.3 Product Modeling Technology

The Odense definition of a product model is a precise description of some subset of the world of interest. For their shipbuilding applications, this is further defined as “a structured assembly of information describing a product completely and precisely.” The complete definition includes not only the traditional CAD focus on engineering definitions of parts, but the entire ship construction process.

The PROduct MOdel System (PROMOS) was developed internally at Odense Steel Shipyard beginning in 1992. A development team of six Odense people and two Hitachi counterparts did the initial development under the direction of the concept originator. This team selected an object-oriented database, ITASCA, for the database management system. IBM's “PEX” was originally chosen as the graphics language but development problems caused a switch to Silicon Graphics “GL” language. The PROMOS system runs on Silicon Graphics INDIGO workstations. The software itself is written in C and C++. The current 4800 TEU vessel contract is the first production application for the PROMOS software.

The original scope of PROMOS was to provide a decision support system to aid in the concurrent development of a complete ship product model and production plans. It would include process manhour requirements to facilitate design/production decisions. The CAD product model itself, including joints and weld lengths, would remain in HICADEC but derivative data (e.g. weld times and costs) would be developed in PROMOS. Currently, some of the development of PROMOS is being driven by the advanced robotic welding programming technology being developed in the AMROSE

project. This requires high quality (e.g. rigorous mathematical definitions) weld paths in order to create robotic welding NC code for shell assemblies. It is considered likely that more CAD/CAM functionality may move from HICADEC to PROMOS in the future. Current capabilities of PROMOS include the following:

- Ž Block assembly breakdown, visualization, and assembly sequence planning
- Ž Design visualization, interference analysis between hull structure and outfitting
- Ž Joint and weld line data generation (including bevel information)
- Ž Transfer of product model data to simulation systems, such as ROBOCAD, and off-line robot programming, such as AMROSE

PROMOS is intended to have a neutral file architecture and function as the core of the current Odense CIM system. It is currently integrated with HullSurf, HICADEC-H, HICADEC-P, and Production Management System (PMS). Product model updates, based on CAD developments in HICADEC -H and -P, are performed on a nightly basis via a batch process.

## 4.6 PLANNING AND CONTROL

The “A-B-C Philosophy” in planning at Odense is described in Appendix B. Initially, the shipyard utilized conventional bill of material (BOM) and parts lists systems. More recently, a decentralized planning system was introduced to facilitate the use of this planning philosophy.

### 4.6.1 PMS System

The Production Management System (PMS) is the primary tool for management of production facilities, resources, and materials used for hull steel construction. It was developed by the Maersk Data group in residence at Odense Shipyard, initially as a bill of materials (BOM) system. It is interfaced with the HICADEC-H CAD system for parts, assemblies, materials, and welding data. It also interfaces with planning, cost control, and production records systems.

The core of this system is a relational database that contains relevant procurement, inventory, and production planning (“C-Planning” assembly and schedule) data. Access to this database is provided over the shipyard LAN to the various functional organizations that supply or use this information. Such organizations include design (material specification), purchasing, steel stockyard, production planning, and numerous part production and assembly halls and workshops. Some 50 terminals distributed around the shipyard access PMS.

The part, assembly, material, welding, and system data developed in HICADEC-H for each block are updated periodically as completed. Part data include all “attribute data” information, such as weight, material type and quality, marking lengths, block number, shaping flags, cutting lengths, parameters for profile endcuts, etc. These data are not used to drive machines in a geometrical NC sense, but rather for manhour estimates and calculation. Plate parts are nested in HICADEC-H, but profiles (shape and part information) are fed to PMS and nested there onto raw material profiles (straight forward, batch operation).

The drawing office uses PMS to material order work operation code, and block address functions. Production uses PMS to do stockyard inventory, stock supply list, job ordering, job review, completion report, manhours report and statistics.

#### 4.6.2 MAPSOS and OSTK

These systems provide the primary tools for outfitting material control and production management. OSTK is primarily a parts list system and MAPSOS is primarily a production management system. The interface to the 3-D product model in HICADEC-P is through the INGRES SQL-compliant relational database. MAPSOS is used for planning production flow, developing upcoming stock material needs, and tracking pipe production.

#### 4.6.3 DPS System

The Decentralized Planning System (DPS) was developed jointly by the PA Consulting Group (London), Maersk Data Systems, and Odense Steel Shipbuilding. It is a graphical planning tool developed for work order processing in one-off production. Initially introduced in 1991, a network version was installed in 1992. In 1993 it was integrated with other Odense systems. It utilizes the INGRES relational database management system and is written in C for use in X-Windows MOTIF on Data General AViiON UNIX workstations. The DPS system is used for “A-Planning” and “B-Planning” only (see Appendix B descriptions). Another PC-based system is used for “C-Planning” in the production shops. The DPS system is commercially available.

The DPS system combines planning of time, resources, area, and tracking in the same tool. The two main modules are a graphical module and a tool module. The graphical module is used for activity planning and detailed resource and workshop planning by both A- and B-Planners. Activity and resource planning are computer-assisted, including the use of rules-based algorithms for estimates and job routing. The Tool Module performs the following functions:

- Ž Data entry
- Ž Reports

- Interfaces to other systems
- Batch jobs
- copying of plans
- Dependencies
- Validations
- Table maintenance
- Internal information

Each user can define/customize the view, sort parameters, and so on. There is an interesting “sister ship” B planning function that allows the user to copy an existing B plan and to modify it for learning curves on follow-on ships. Different learning curves can be input for each trade by percentage. This function reduces the manhours/task but not the duration of the tasks (much more complex to calculate because of yard dependencies). The user can switch the display resolution between A and B levels; that is, showing one activity per block or one activity/block. Group functions allow multiple tasks to be moved, deleted, etc. Each activity can be given a daily work profile by discipline. For example, welders may be assigned for only the last 80 percent of an activity. A cycle planning function allows selected skills to be optimized and analyzed for potential problems.

The area planning function also has a very user friendly, state-of-the-art GUI. The top part of the window depicts a plan view of a shop, e.g. assembly area. The building floor is dimensioned, labeled, and broken up into work areas or cells. At the bottom of the screen are scaled polygon representations of the structural units (Based on schedule information). The user drags the assembly symbols into work areas. The symbols can be rotated and manipulated within the cell as would be expected in a GUI system. Based block and cell size will not let the user drop a block in a work area that is too small. The system does not verify block weight to gantry lifting capacity over the work cells, but this functionality may be added in the future.

The window gives the shop plan for a given day on the schedule. The view can be turned forward or back to show changes or progress with a mouse click. Colors are used to indicate block status - blue for the first day the block enters the shop, pink for the following days, green for the last day, and orange for a one-day activity. The system offers bidirectional functionality between the area planning function and the planning function; changes made in one are automatically reflected in the other.

#### 4.7 CAD/CAM/CIM INTEGRATION

The HICADEC system is only a basic foundation component of the Odense CAD/CAM/CIM systems. It is basically the 3-D geometric modeling tool with often

limited support to associated attributes. Odense has developed a host of integration tools for information exchange both within Odense (between design disciplines, materials control, purchasing, production, etc.) and with vendors and subcontractors.

Hitachi maintains the HICADEC software as directed by Hitachi, Odense, and one other unidentified Japanese shipyard. Hitachi will deliver versions with needed modifications within two weeks if necessary. Odense and Hitachi maintain an ISDN high performance telephone connection, which is used by Hitachi to access the Odense system and load new versions of HICADEC overnight as necessary. There are ten HICADEC programmers at Hitachi providing the CAD/CAM software maintenance and development services.

The products of the CAD/CAM systems are checked and corrected as necessary by a small group (five people) in the Production Planning Department. This group provides some quality assurance function on the design products and also determine production standards (hours and/or Krona) appropriate for the production processes required to complete work tasks.

#### 4.7.1 Hull Structure

The structural group occupies very clean and tidy office space, which is carpeted and well illuminated. Some 50 Data General AViiON workstations, each with a Wacam tablet, are arranged in a single area on one floor. The tablets have wireless digitizers and pen-like pointing devices. Each designer has ergonomic furniture including an L-shaped work area with the workstation on a special corner desk.

In the design phase, basic hull form development and structural framing concepts are defined using third party software tools. First structural sketches (i.e. midship section, etc.) are developed followed by final hull fairing and drawings used for classification review. The third party tools used include the following:

##### Hullsurf {from BMT}

Ž hull lines development and fairing, including preliminary hydrostatics, stability, and speed./power considerations

##### NAPA

Ž Production-level hull firing and design calculations for hydrostatics, stability, compartmentation, etc. This software was added about 2 years ago. Odense previously used FORAN hydrostatic calculation software, which was purchased in 1982.

##### NISA

l Finite element analysis (FEA) of hull structure

In the engineering (detailed design phase, GRADE/G and HICADEC-H are utilized along with related in-house Odense software tools (e.g. PROMOS, INGRES, etc.]. Three separate databases are used for the fore, aft and deckhouse areas. Production information is also developed during this phase utilizing ROB-IN and PMS. These software tools and their use can be characterized as follows:

GRADE/G

Ž layout

PROMOS

Ž Software developed by Odense that facilitates integration of the hull structure and outfitting product models. Also accesses product model data for cutting and welding length data used for costing evaluations.

HICADEC-H

Ž Primary 3-D product modeling system using surface modeling (wire-frame) methods.

ROB-IN

Ž ŽROBotics INput (ROB-IN) system was developed by Odense to take CAD data from HICADEC and generate robotic instructions.

PMS

Ž Project Management System (PMS) is a separate module containing information for material ordering and workshop production. It also is used to maintain total manhours and total production information.

#### 4.7.2 Outfitting

The outfit design group occupies clean and professional office space in an open (no partitions) arrangement. They have some 40 Data General AViiON workstations installed with good ergonomic work spaces. During the NSRP team visit the outfit design group was down in number since the current shipyard work involved building nine identical container ships. During heavy design workload periods, one third of the designers are blue collar production workers. This approach to staffing the design office was found to enhance design for production.

Outfitting design begins during the design phase with major machinery (e.g. main engine, generators, etc.) decisions, system diagrams, initial arrangement drawings, and specifications. Typically, layouts and arrangements are initiated after the hull form and basic structural configurations are developed. 2-D CAD tools (GRADE/G) are used for layout/arrangements. The general arrangement is used to help guide the build strategy

lock break-outs and preliminary preoutfitting decisions. Specification information is provided to vendors for pricing information and technical data needed to support the subsequent engineering phase. Little or no computer-aided functional performance engineering seems to be done during this design phase. Mention was made of utilizing Lloyd's for vibration analysis.

Process information diagrams (PID) are prepared for all major ship systems during this design phase. These are done utilizing the 2-D diagram capabilities of HICADEC-P. Electrical diagrams are developed using AUCO PLAN, also in 2-D. The HICADEC-P software offers a rich library of pipe definitions and catalogue components (e.g. valves) with graphic symbols tied to an associated list of attributes contained in a "Part Dimension File" (PDF). Each component selected for inclusion in a PID is referenced by a part code. Use of standard pipe sizes is encouraged. Once the PIDs are completed, material lists can be output for use by Purchasing.

Pipe and components in each ship's system can be segregated within the HICADEC-P diagram according to the construction blocks in which portions of the system will be physically located. This capability is used for very early reconciliation of the outfitting design to the build strategy. It permits package unit constructions to be identified early in the process and is used to develop preoutfitting strategies very early in the design phase. Color coded displays are used to help visualize these block break-downs. Once the block break-downs have been completed, material lists can be output by block or for the entire ship. These material lists are quite complete, providing design and specification information for each component code along with quantities broken down according to nominal sizes.

In the subsequent engineering phases, 3-D product models are developed utilizing HICADEC-P. Little associativity other than line numbers and block assignments is maintained between the 3-D product model and the 2-D system diagrams. Attributes of components (e.g. valves) generated in the diagram development can be referenced in the 3-D product model. Libraries of equipment and components are provided for this modeling. Previous models for earlier ships can also be retrieved and modified. Additional equipment models can be developed using the basic primitives available in HICADEC. Standard component (e.g. valves) libraries are well developed. They include automatic assignment of appropriate flange and gasket materials when used to construct the 3-D product models.

The initial 2-D arrangement drawings are used to guide the development of the 3-D product model. Hull form and structure model data are obtained from the HICADEC-H hull model via the PROMOS software. The databases (hull and outfitting) are not integrated, so the hull data must be updated periodically to reflect additions and changes made by the Hull Structure designers.

HICADEC-P provides for interference checking (batch or interactive) only within the outfitting model. Periodically, checks for interference with hull structure must be done using the PROMOS software. Interferences detected by this system are resolved manually; penetration lists are provided to the hull structure department. HICADEC-P also makes some production simulation checks. For example, the designer is warned if a spool has insufficient straight length on each side of a pipe bend to permit clamping in the pipe bender. “Move flanged joint” or “provide extra length” advice is provided. Long straight runs in curved spools can also be checked for pipe shop interferences in the vicinity of the pipe bender.

A key pipe shop productivity practice is the welding of flanges onto both ends of pipe spools prior to bending. This requires precise detailing and proper accounting for as-bent lengths and dimensions. Likewise, it also requires attention to flange bolt hole orientations. The production simulation checks described above also contribute to the use of this practice. “Spring back” tables, based on empirical data, are maintained for standard pipe sizes in order to provide accurate workshop instruction information.

Computer-aided engineering (CAE) tools are used to validate functional performance during the engineering phase. Specifically, steam systems are analyzed for thermal expansion and stress using the NISA finite element software. System calculations (e.g. pressure drop) are done on a number of systems, reportedly using HICADEC-P tools.

In the Outfitting CAD area, the primary tools include GRADE/G, HICADEC-P, AUCO PLAN, and PROMOS. These tools are illustrated in Figure 4.5 and can be characterized as follows:

#### GRADE/G

- Ž layouts, diagrams, arrangements, and drawings used in preliminary design and where full 3-D modeling is not warranted in detailed engineering (e.g. accommodation arrangements).
- ŽŽ Ž Extracts data from the 3-D product model and generates arrangement and detail part drawings.

#### HICADEC-P

- Ž capabilities used for systems diagrams other than electrical
- Ž Primary 3-D geometry modeling tool (wire mesh and solids primitives). Used for the outfitting 3-D product model including piping, cable trays, and HVAC locations.
- Ž Produces piping isometric sketches and drawings complete with numeric dimensions in tabular form.

#### AUCO PLAN

Ž CAD system for electrical diagrams. This software is third party software believed to be obtained from Germany.

#### PROMOS

1 PROduct MOdel System (PROMOS) is an Odense software development.

Currently, it provides the interface between the HICADEC-P outfitting product model and the HICADEC-H hull structure product model. The goals for further development of PROMOS include implementation of CE and IPPD design philosophies via decision support systems.

The PROMOS software appears to be the primary CAD integration tool between disciplines (hull structure and outfitting). Normal practice seems to be to update the “cross-discipline” data at the end of each day.

#### 4.7.3 INGRES

INGRES is an SQL-compliant relational database used to exchange data from the HICADEC system to material control and production planning systems.

In outfitting, this database provides the interface between HICADEC-P and both the part list system (OSTK) and the production planning system (MAPSOS). This database is used to store material and production status information along with revision control data. The data are organized by piping isometrics, which are assigned a unique number for each isometric drawing.

#### 4.7.4 MONMOS

The MONMOS system is used for dimensional control based on infrared measurements.

#### 4.7.5 ROB-IN

ROBOTics INput (ROB-IN) system was developed by Odense and a local software vendor to take CAD data from HICADEC and generate robotic instructions. The system produces the NC instructions for flat panel assembly robots. It is currently being used at Odense, Hyundai, Sarnsung, Danyard, and a shipyard in France. The software runs on DOS-PC platforms, primarily 486 and Pentium PCs. The operation of ROB-IN is outlined below:

1. The first function performed is IMPORT. An IGES file containing wire frame data of the structural subassembly is loaded from HICADEC. A graphical view of

the imported wireframe model is then presented. The system knows which lines are welds and which are just representative of the structure itself.

2. ROB-IN breaks up the structural assembly/block into “supercell” - a logical zone of work for one robot to perform a group of welding tasks. User changeable runs define the criteria by which the system determines the supercells.
3. Using a mouse, the operator cleans up any translation errors and/or modifies or combines welds as appropriate.
4. Using a mouse, the user clicks on the welds that they would like grouped into a single weld job. Up to eight welds tasks are typically grouped together in this manner. The order of selection is not important. The rules will specify actual NC sequencing of the job.
5. A batch type function is then executed that geometrically scans each weld joint for a match in the joint library (user can customize). The library defines all the other parameters, which when combined with the wireframe joint geometry, enable a sufficient NC file to be generated.
6. An NC file is then generated and stored on the server. A “task file” provides the information necessary for the system to identify the most appropriate robot for each job (based on gantry location and sequencing). The NC file is processed locally on the shop floor by the ROB-EX application running on a Sun SPARC Station. It is this system that actually drives the twelve robot controllers.
7. Production information, such as planned weld footage, weld time, and other statistics, is automatically transferred to PMS Planning and Scheduling system for the IGRES RDBMS server. This information is used by shop planners. For example, it would tell them how many robot operators would need to be on hand. ROB-EX then updates the INGRES database with actual weld footage. They are currently working on quality monitoring software to store data on weld quality (e.g. 7 meters of weld needed touching up, and porosity). This type of information would help them identify problem areas in the welding hardware and software.

#### 4.8 R&D PROGRAMMS

Participation in R&D programs leading to more efficient processes is top-down driven from the CEO level. The specific programs and implementation decisions are influenced by production line ideas for new methods and/or systems. European

Community (EC) joint research projects appear to provide funding and collaboration environment for much of the precommercialization base technology development.

#### 4.8.1 Current Shipyard Projects

A robotic pipe welding application is being demonstrated using a STEP protocol product model and sensors to drive a REIS robot welding a large pipe interconnection (a Tee). Quality and consistency was extremely high and Torben Andersen claimed it to be better consistency than his best welders. This robot is expected to be released to production shortly.

A longer range (five year) R&D effort is underway (with EC project support) to develop a “smart welder.” This robot will use an infinite number of axes snake manipulator to access any area. The goal is to eliminate robot programming (on-line or off-line). The system will require only CAD model input (geometry, sequence, and types of welds) and the robot will determine its own tool path and weld parameters. This approach requires real-time computations and will need high performance computing resources to become practical in production. The expertise for this project and others is claimed to be entirely in-house (undoubtedly including Robitec). Torben Andersen claimed that no robotics firm had the expertise to develop this capability. It appears that use of agent-based programming is a key feature to this innovative robotic welding technology. Additional information about agent-based programming, and its application to welding and production scheduling, was obtained by the NSRP project team through a visit to the Industrial Technology Institute (see Section 15.1).

#### 4.8.2 International Joint Research Projects

Odense has been active in international (mostly EC) joint research projects for some fifteen years. The ESPIRIT program was first, not achieving the technical objectives of the project, but starting cooperative R&D that continues today. Currently, Odense supports a 20-25 person (full time) development group at the shipyard focusing on robotics and CAD/CAM/CIM technologies and integration. Half of the funding to support this group is from Odense and half derives from EC cooperative R&D projects. The actual people involved at any onetime are from a group of about 50 people. Those not doing R&D are involved with design or production. In total, the current EC projects amount to about \$15B (14B ECU), primarily involving software (i.e. mostly salaries). Most of the base technology and demonstrations of Odense’s robotics applications have been supported by these EC projects. Typical projects range in size from 20 to 120 man-years of effort by project teams.

Some of the EC joint research projects and other (Government sponsored) projects in which Odense has or in which it is participating areas follows:

- Flexible Low Cost Automation of Arc Welding (1986-90), used more in Japan
- HIRO - Neutral Interfaces for Robotics (1990-92), avoid Siemens “monopoly”
- MOSAIC - Modular Open System Architecture for Motion Controller (1990-92)
- PROMISE - Architecture for CIM, modeled hull design and processes (late 1980s)
- MIRCON - Modular Industrial Multi-Robot Controller (1994-96)
- Application of Vision Technology to Order-Producing Industry (1993-95)
- INTERROB - Robotic Communication STEP and IRL Standards (1993-95)
- Models and Methods of Cell Control in Heavy Industry (1992-95)
- AMROSE - Autonomous Multiple Robots Operating in a Structured Environment
- Classification of Laser Welding in Shipbuilding (1993-95)
- Laser Welding and Prototype Sensor Expert System for Process Control and Monitoring (1992-95), Meyer Werfpursuing for thin plate welding
- CLEOPATRA - Programming & Control of Multi-Axes Welder by Vision (1994-95)
- CAESAR - Analysis and Optimization of Manufacturability of a Complicated Product Before Completion of Design by High-Performance Computing (1994-95)
- Concurrent Engineering (CE)
- Global CE for Different Kinds of Industries (1993-96)

In addition to EC and Danish Government programs, Odense pursues Sasacowa Foundation research finding and Nordic countries finding for environmental projects.

#### 4.8.3 Odense 5-Year Development Plan

The 5-year plan for Odense future development includes the thrust areas described below. These thrust areas were compiled from comments made during a “meet the top management” question and answer session, and from comments made by some of these people and others over the course of the NSRP project presentations, tours, and demonstrations.

- 1 More complete product modeling including integration with shipyard modeling, especially in the robotics areas.
- 1 Increased automation in the design process. Utilize logical “rules” to facilitate the CAD process and concurrently incorporate production process considerations.
- 1 Integration with economic decision making.
- 1 Improved cost/performance computing hardware (e.g. parallel processing, enhanced visualization aids, lower cost platforms). Speed of developing information and evaluating alternatives with consideration of production costs is felt to require improved computing resources.

- Ž Bar coding for material control. (Evaluation and prototype testing has been done, but implementation awaits budget allocation).  
Painting robots are currently being investigated. Torben Andersen indicated that he believes Odense will utilize robotic painting facilities within a year or so. He **also** indicated that his opinion is that robotic blasting has more pay-off potential, but that Odense will probably defer looking at this area until the painting robotics have been implemented. Cleaning robotics are being considered but not yet investigated.
- Ž The pipe shop was described as utilizing older automation technology and will likely be the subject of a Mure development project. No specifics were offered.
- l Continue to increase the automation of welding as economically justified through the use of advanced technologies such as mathematical off-line and real-time robot motion specifications. These technologies require 3-D product modeling for the mathematical representations.
- Ž In the welding robotics area, correlation between weld porosity and a monitorable weld process parameter is needed to facilitate quality assurance. In addition, knowledge-based rules must be implemented and revised based on on-going experience.

#### 4.9 PURCHASING AND VENDOR RELATIONSHIPS

Supplier cooperation is a key feature of Odense's approach to shipbuilding. Suppliers are required to meet prespecified quality, test, and delivery criteria in order to remain preferred suppliers. Multiple suppliers are often used (e.g. seven steel suppliers on VLCC newbuildings) to ensure supply of needed materials. ISO certification is not required providing vendors can perform to ISO 9003 using their own QA./QC systems. Penalties for noncompliance are incorporated in each procurement contract. Categories of noncompliance, such as late drawings or design information, late materials, reject materials, and out-of-spec materials, are used with different economic penalties. Design review rights (i.e. access to vendor's internal documentation affecting quality and/or delivery) are also written into purchase agreements.

Emphasis is placed on vendor's workshop testing to prove correct functioning prior to acceptance by Odense. Another feature of Odense's purchasing practice is that vendors are required to furnish items tagged according to the yard's item list.

Procurements are divided into three categories based on value to a successful shipbuilding. These categories are described below.

Category	<u>Total Number of Parts</u>	<u>Total Value</u>	<u>Criteria</u>
"A"	10% (about 150)	85%	over 100,000 DKr
"B"	15%	10%	over 50,000 DKr
"C"	75%	5%	under 25,000 DKr

The "A" category purchases are assigned to Engineering/Purchasing teams to ensure technical adequacy at minimum purchase costs. Generally these teams negotiate the requirements, criteria (and penalties), and costs/schedules with two suppliers. Vendor selections are made early in the design phase so suppliers can cooperate with timely and accurate information as well as possible design alternatives. For steel and pipe material suppliers, just-in-time delivery agreements are made based on approximate total quantities for a newbuilding project. Specific material requirement forecasts are shared with these vendors eight to twelve weeks ahead of delivery needs.

Historically, most suppliers are from Denmark, Japan (steel), UK, Nordic countries, and Germany with Denmark accounting for almost half of this work. A conscience effort is being made to increase the work content by Eastern European (Estonia, Poland, Romania) and Far East (Korea, China) suppliers. Historically, these nations have participated in less than 0.25% of Odense's business. This percentage will be over 3.0% on the current 4800 TEU contrac, and Odense's target is to increase this percentage to 10.0%. Limited experience with vendors from these nations has been generally positive and it is believed that significant cost advantages can be realized.

1 Building docks nos. 200,000 tds  
2 Material receiving quay  
3 Yard for plates  
4 Yard for profiles  
5 Shotholing  
6 Profile fabrication  
7 Plate cutting  
8 Assembly of rectangular blocks  
9 Assembly of components  
10 Assembly of curved panels  
11 Assembly of curved blocks  
12 Paintshop  
13 Administration  
14 Goods reception and warehouse  
15 Apprentice school  
16 Component workshop  
17 Pipe workshop  
18 Outfitting -Unitall  
19 Outfitting basin nos. 200,000 tds  
20 Outfitting quay  
21 Block assembly  
22 Block storage  
23 Block assembly  
24 Guntry cranes 1,000 tonnes  
25 Building docks nos. 100,000 tds

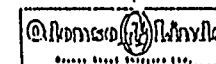


Figure 4.2 Odense Shipyard Aerial View

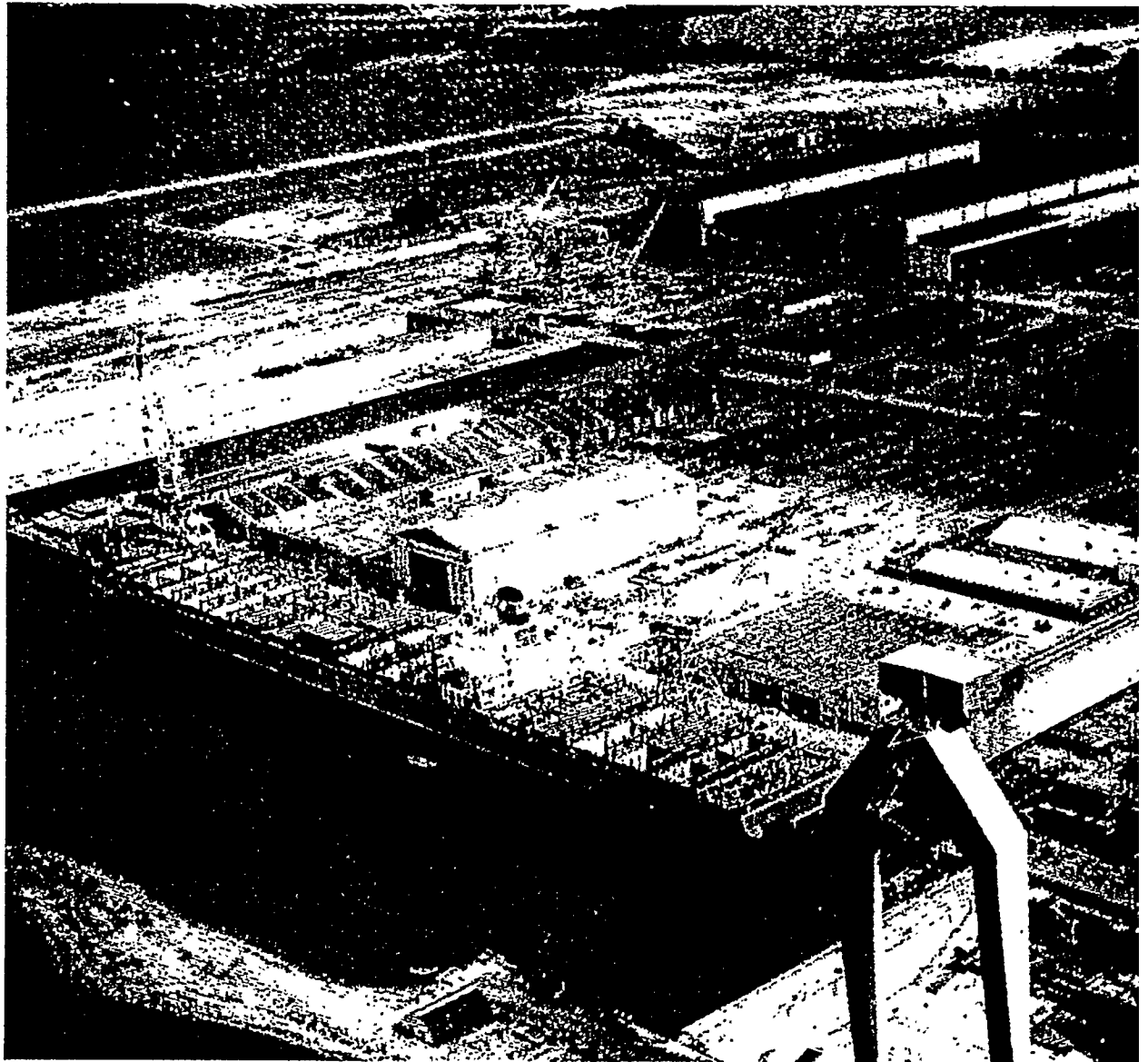


FIGURE 4.3 PRODUCTION PLANNING INFLUENCE ON COSTS

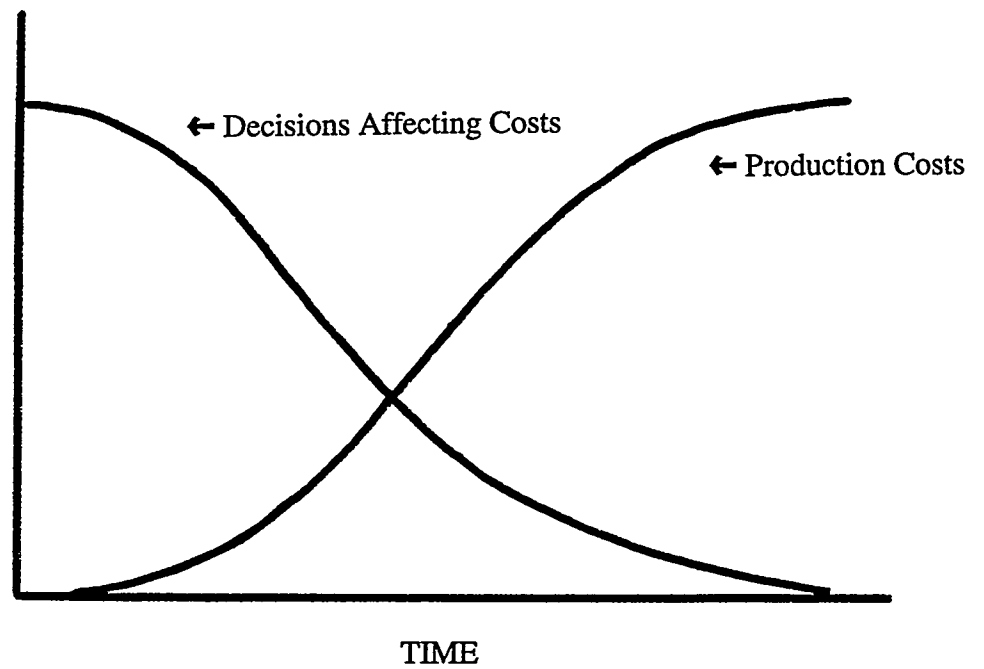


FIGURE 4.4 MATERIAL "INVENTORY" COSTS

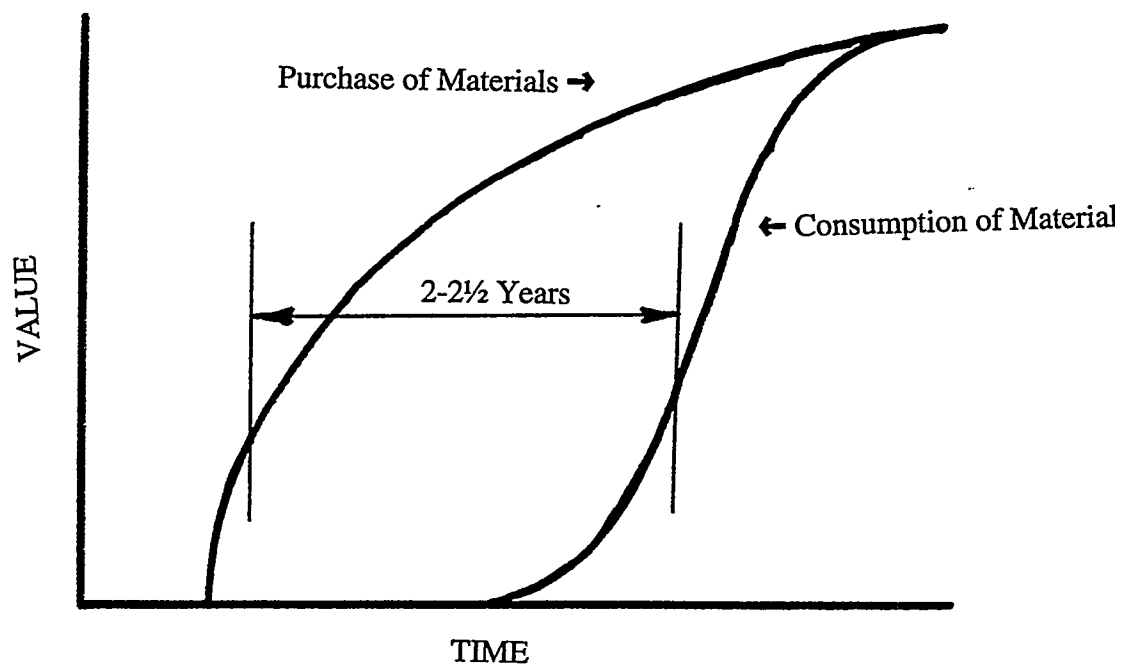
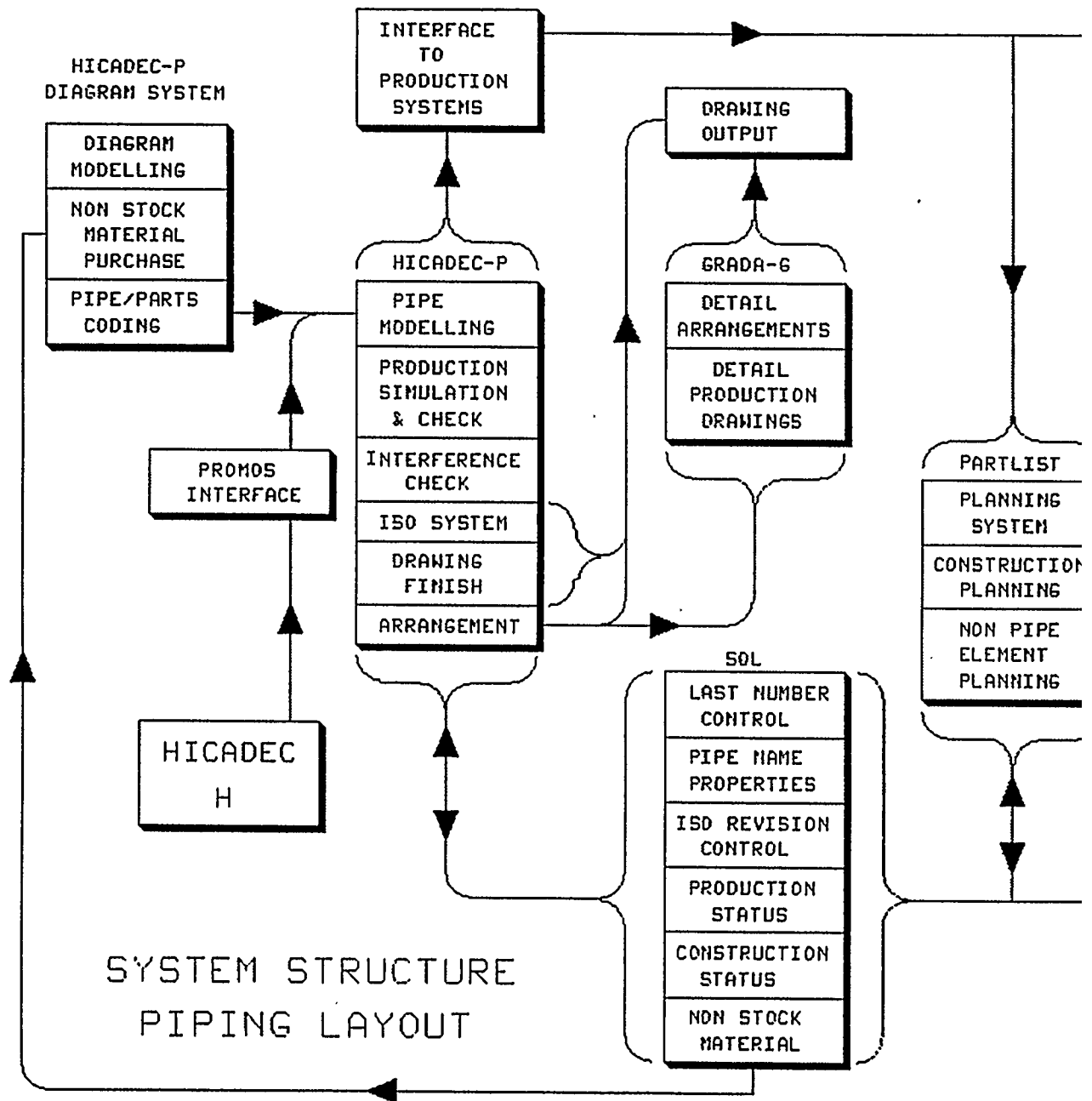


Figure 4.5



## **5.0 MITSUBISHI HEAVY INDUSTRIES, LTD.**

### **5.1 NAGASAKI SHIPYARD OVERVIEW**

The Nagasaki Shipyard & Machinery Works provides some of the principal facilities for shipbuilding within Mitsubishi Heavy Industries, Ltd. (MHI). About 35 percent of the \$5B annual production at these works is related to shipbuilding. Shipbuilding and steel structures revenues account for about 18 percent of MHI's \$25B annual sales. The main plant (see Figure 5.1), located in southwest Nagasaki, began work as a foundry in 1857. Two 300,000 DWT drydocks were completed in 1965 for shipbuilding and repair. Completed in 1972, the Koyagi plant (see Figure 5.2) is the showcase facility with a 1 M DWT building drydock served by 600 ton gantry cranes, and significant factory automation including large robotic welding facilities and newly introduced (1 year) robotic cutting facilities. This facility is located just south (a few kilometers) of Nagasaki. A number of smaller shipbuilding and repair yards and steel fabrication works occupy sites around the harbor in Nagasaki and southwards. Some of these smaller yards do subcontract work for MHI, which provides additional flexibility to overcome anticipated production bottlenecks.

The MHI organization is shown in Figure 5.3. The major shipyard works, including Nagasaki, report directly to the MHI President. Marketing, Project Management, and Product Development Engineering for shipbuilding is handled through the Shipbuilding & Ocean Development Headquarters in Tokyo. Research & Development is centrally organized, but the actual facilities are generally colocated with major business units. For example, the Nagasaki R&D Center occupies facilities located adjacent to the Koyagi plant.

The total Nagasaki Works employment is about 7650 with about 1200 shipbuilding employees each at both the Main Plant and Koyagi Plant. These numbers include about 300 designers, 100 production engineers, 20 software systems support, and 30-40 factory automation personnel. The 50-60 software and automation personnel are scheduled for downsizing.

### **5.2 BUSINESS STRATEGY**

MHI shipbuilding projects tend to be primarily "one off" projects with an occasional multiship series construction contract. Large vessels, often involving considerable complexity (e.g. LNGs, etc.), are featured, which utilize the large drydock and crane capacities of the shipyard. In parallel with these commercial efforts, MHI builds an average of one defense force vessel every two years. This was characterized as pretty steady work building similar vessels (Aegis destroyer escorts). During our visit

work was underway on two large container carriers, an LNG carrier, an FPS conversion, an LPG repair, and a storage barge. An Aegis escort vessel was dockside.

The design features being pursued for competitive ship products emphasize the following areas:

- Ž Automated and energy efficient ships
- Ž Faster and more maneuverable ship designs

### 5.3 COMPETITIVE STRATEGIES

#### 5.3.1 Ship Design Systems

At the initial design stage, a highly integrated system, Mitsubishi Advanced Realtime Initial Design and Engineering (MARINE), is used to quickly develop derivative designs based on existing databases of completed ships. Performance calculations (e.g. hydrostatics, stability, speed/power, strength, etc.) are completed using application programs integrated within MARINE. A spider diagram approach is used in which trade-offs between various performance features, costs, and customer requirements and preferences are effectively resolved. The DAVID information system is used in conjunction with MARINE to facilitate use of proven approaches in developing new designs. Drawings, outline specifications, and cost estimates are produced by the MARINE system.

At the basic and detail design stage, the large libraries of CAD data are utilized to assemble 3-D product model descriptions of the new ship design. The MATES system, introduced in 1986, is the primary CAD system. Within MATES, large CAD libraries of previous ship designs, standard components, effective outfitting packages, and vendor-supplied components are maintained by MHI. New ship hull designs are efficiently defined from MARINE system data or variations of parametric databases of previous ships. Outfitting design is developed through reuse of successful packages from previous designs. New piping arrangements are generally custom developed with consideration to the new hull structure and outfit packages retrieved from databases of previous ship designs.

The highly integrated MARINE/DAVID/MATES capabilities provide MHI with competitive advantages for one of a kind shipbuilding.

#### 5.3.2 Flexible Labor Resources

The workforce and management consists of (unionized) MHI personnel, subsidiary company personnel, and on-site contractors. All production is generally

planned on a “first shift only” basis. Agreements with labor provide for eight, nine or ten hour workdays as required to maintain production schedules. Neighboring firms in the Nagasaki area are used to augment the shipyard capabilities. For example, Kyushu Steel K.K., a large steel fabrication plant adjacent to the Koyagi plant is used to provide plate steel products as appropriate to production needs.

One of the demographics that is driving the MHI developments in CIM and factory automation is the declining base of skilled workers. Current practice is to provide “sketchy” work instructions which are suitable for most of the existing skilled workforce. CIM systems are being developed, integrated with the existing CAD/CAM systems, to quickly and accurately produce detailed workshop instruction packages suitable for a less skilled workforce. For example, 2-D drawings (3-D model projections) are currently used in production. These are scheduled to be supplemented with 3-D isometrics and pertinent parts lists for each fabrication process. In addition, factory automation efforts are driven by this increasing scarcity of skilled workers. It is understood, however, that total automation of all assemblies will never be possible. Human minds will always be needed to cope with many of the more complex and less repetitive assemblies.

### 5.3.3 Factory Automation

Despite a product mix that includes many one-off vessel construction contracts, considerable investment in large robotic welding stations was evident.

Painting trials with painting robots have been successfully demonstrated for inside the double bottom via these same access holes. Implementation of robotic painting, based on the results of these trials, is expected to be accomplished in the next couple of years.

### 5.3.4 Computer-Integrated Management

Since 1986, MHI has participated with six other Japanese shipyards in the “Frame-Model” CIM project intended to develop a more integrated approach to shipbuilding automation. The current thrust of this project appears to be the development of a General Product Model Environment (GPME) based on a central product model database. Figure 5.4 illustrates the Nagasaki Shipyard CIM concept and how it integrates many shipbuilding functions. The drivers influencing CIM development were described as follows:

Ž Shipbuilding was described as a tailor-made industry - making a few custom products involving a very large number of parts for individual customers. This was described as quite dissimilar to the auto industry, which utilizes prototypes and makes large production runs of products involving a moderate number of parts. Figure 5.5 illustrates these differences. Shipbuilding was characterized as

more similar to the power plant industry in which the “prototype” is the final product delivered to the customer.

- Skilled workers are expected to become increasingly scarce with the workforce requiring more explicit process instructions. Current practice provides only sketchy data for the highly skilled workforce.
- Increased worker productivity required to maintain or increase profits in markets that are not expected to sustain price increases.
- Need for timely intermediate product data to support production planning. This is currently not available in a timely manner from traditional CAD/CAM systems. Support for the “Frame-Model” CIM project appears to have been provided by the Sasakawa Foundation.

#### 5.4 AUTOMATION

In support of double-bottom tanker fabrication, two significant robotic welding facilities were observed that reportedly came on-line about a year ago. A “flat panel” assembly facility provides for robotic welding of stiffeners and frame elements to one of the hull skins using gantry mounted welding robots. The stiffener welding facility has 8 gantry-mounted robotic heads (PanaRobo?) in a linear array along a motorized conveyor. Robotic paths are generated by off-line teaching based on data provided from the MATES CAD/CAM system. The subassembly welding station has four single-head gantry-mounted robotic welders arranged in two bays. Sketches of both of these facilities are provided in Figure 5.6.

The second hull plating is welded to “egg crate” assemblies of first hull plating with frames and bulkheads in another robotic welding area. Final assembly welding is accomplished by a robotic welder using a horizontal arm inserted in access holes through the floors to reach the floor-to-skin and stiffener penetration weld lines.

#### 5.5 MAJOR CAD/CAM/CIM SYSTEMS

Mitsubishi Heavy Industries (MHI) has been working to apply process automation to achieve cost reduction over the last 30 years. Software tools have been mostly independently developed. Introduced in 1986, MATES provides most of the CAD/CAM functionality of the MHI software systems. Its development continues for enhanced functionality.

MHI’s approach to CAD/CAM/CIM has been mostly home grown. The MARINE and MATES systems provide the bulk of their CAD/CAM capabilities with MATES being the functional equivalent to FORAN, TRIBON, HICADEC, etc. MARINE is concerned with preliminary design and naval architecture calculations in

support of their marketing and proposal efforts. It was developed after an evaluation of KCS and Senermar (FORAN) CAD/CAM systems, which concluded that model building in these systems was too laborious to support preliminary/functional design.

Development efforts for these systems involved a staff of 100 for periods of three years each. Current maintenance and enhancements are handled by twenty support personnel; ten for MATES and ten for the PMS production management system.

The overall MHI implementation is illustrated in Figure 5.7. The MATES and PMS systems are in use, but the connection between these systems is characterized as weak at the current time.

#### 5.5.1. MARINE

The Mitsubishi Advanced Realtime INitial design and Engineering (MARINE) system is utilized to develop rapid responses to customer inquiries. It utilizes the Dynamic Administration with Value Integrated Database (DAVID) information system, which uses effective past designs and design practices to the fullest extent possible. MARINE is used to develop preliminary product descriptions only to the extent necessary for estimating naval architecture and performance features (displacement, capacities, strength, speed/power, engine/generator requirements, etc.). Preliminary cost estimates are developed and development needs to assure performance factors are identified. General arrangement drawings, specifications, cost estimates, and performance calculations are produced by this system.

The MARINE system is menu driven and highly integrated with performance calculation software packages. A demonstration for container ship design was observed. First, a “standard” hull form was wrapped around container loading patterns (width and height) at each bay. This information was then used with various loading assumptions (tons/container) for preliminary stability and longitudinal strength (bending and shear) calculations. Next, initial design specifications (speed, endurance, etc.) were input followed by main engine and tankage selections. The MARINE software computes margins for each specification requirement based on current selections. At this point in the design development, hull form characteristics (resistance, etc.) from similar existing designs were assumed in computing margins. Due to limited workstation computational speed, the demonstration could not include actual design iterations within the allotted time.

Once the preliminary sizing effort is completed, the next stage of the MARINE software provides for creating preliminary lines and more precise consideration of hydrostatics, freeboard, tonnage, speed/power, strength, and stability. The computed margins are used to track expected performance compared with customer minimum requirements and desired “stretch goals.” The margin tracking capabilities of the

MARINE system appears to be quite effective in resolving the cost versus performance issues with prospective customers. It is used primarily at MHI's Shipbuilding and Ocean Development Headquarters in Tokyo.

#### 5.5.2. DAVID

Very little information was provided about this system. It appears to be an information system used primarily by the Shipbuilding & Ocean Development groups in Tokyo in support of product design and or inquiry estimates. It appears to provide data based on previous MHI experience supporting use of "best design practices" in new product offerings.

#### 5.5.3. MATES

Development of the Mitsubishi Advanced Total Engineering system of ship (MATES) CAD/CAM system began in 1983 and has been in use since 1986. MATES consists of a hull system and an outfitting system integrated with a common database. A number of programs permit acquisition of CAD data developed on other systems; for example, AutoCAD data in IGES format. No commercial software was used (e.g. ACIS graphics) in the development of MATES; it consists entirely of MHI developments. The objectives of MATES development were to:

- Ž save design manhours and shorten the design period,
- Ž save material (plate and pipe) weight through improved design accuracy,
- Ž decrease manufacture of incorrect parts, and
- Ž establish the core information system for future shipbuilding systems.

The hull system is described as a hybrid 2-D (for bulkheads and decks) and 3-D (for hull plating) system. The outfitting system is described as a 3-D system. The CAM features include generation of developed parts, dimensional allowances (e.g. cutting tolerances, weld shrinkage), edge preparations, nesting, 2-D production drawings, and NC cutting data. Other "production support" capabilities include generation of welding robot control data and parts lists, welding length and weight data, painted areas, and pipe counts for use in production scheduling.

All libraries and standards within MATES are developed with consideration to (1) Japanese Industrial Standards (JIS), (2) MHI design standards, and (3) yard production practices. The rationale is that the MATES user is a designer, not a production engineer. Consequently, the standards libraries need to reflect production practices and preferences in order to achieve a producible design.

Nagasaki shipyard currently has no systematic way to feed back dimensional data to the CAD system. They have an interest to add this capability in order to assess where (which process and/or fabrication stage) departures from the accuracy plan occur.

#### 5.5.3.1 MATES Hull System.

Key features of the MATES hull system, which permits rapid development of new ship product definitions, are the topological modeling capabilities, and libraries of parametric-defined regional structural patterns. Topological modeling is used extensively for hull structure definitions to facilitate design alterations and new product development based on derivatives from previous designs. Detailed structural data, such as endcuts, notches, cutouts, etc., all based on consideration of shipyard preferred practices, are stored in standards files.

The structural patterns approach permits creation of similar designs very efficiently, and ensures incorporation of producibility features based on shipyard design/production practices. An example is shown in Figure 5.8. A typical frame section is shown at frame #84, perhaps associated with a previous ship design. A similar frame can be regenerated (copied) to frame #71 with most of the structural detail regeneration being automated including fitting to the new hull lines at frame #71. Similarly, production information can be copied to similar frame sections. Structural library patterns can be modified or new ones introduced as deemed appropriate.

Structural patterns can be developed using topological modeling. This enables automatic regeneration of parts resulting from design changes. For example, the transverse frame shown in Figure 5.9 is changed to decrease the size of the opening. The lengths of appropriate stiffeners are adjusted automatically.

Finite element analysis (FEA) tools are highly integrated with the MATES system. The NASTRAN program is used for FEA calculations, both for strength and vibrations. Tools within MATES are provided for automatic mesh generation using both “hard” and topological geometric descriptions in the product model database. Similarly, static load data are also generated automatically from MATES tank data. Loads based on wave motions can be considered, but must be computed by methods not automated within MATES. NASTRAN analysis results can be retrieved and used with additional MATES applications software to evaluate panel buckling strengths based on classification society rules. Substructures such as panels can be modeled and analyzed for vibration frequencies using FEA methods. Fatigue strength analysis is currently not automated but is completed by manual calculation methods.

### 5.5.3.2 MATES Outfitting

The MATES outfitting system database includes machinery arrangement, process and instrument diagram (PID) data, and detailed 3-D product model data. The 3-D product model data are linked to the PID such that changes (e.g. line rating or valve selection) to the PID are updated in the 3-D model. Topological modeling is used in outfitting to maintain the spatial relationship between piping and equipment. If the equipment is moved, the location of the piping is automatically updated. Each pipeline has a defined size. If changed, all individual pipe segments, flanges, valves, and other components in the pipeline are updated to the new size with a single command.

Nagasaki Shipyard maintains a 3-D model library of standard component products, based on information provided by the component vendors. A priority table is maintained within the MATES system based on shipyard preferred production practices. Examples include preferences for bends, elbows, types of reducers, etc. A well developed degree of automation in product modeling has been incorporated. For example, the designer need only define pipes on each side of a pipeline size change. The software automatically fits an appropriate reducer section to the pipeline, based on component library data and the priority table.

Similar to the structural patterns used to facilitate hull design, the outfitting systems provide for copying outfit modules from a standard module file or a previous ship design. These 3-D model modules are modified automatically if different pipe specifications (e.g. size) are to be used in the new ship design.

A pipe stress analysis package is integrated into the MATES outfitting system.

Once a pipeline location has been finalized, a MATES function is used to define spool breaks and connection flanges based on suitable lengths for efficient manufacture with the current shipyard facilities. Considerations include clamp lengths for the pipe bender, finished spool size for the galvanizing basin (where appropriate), welding and inspection access, and painting of branch pieces after welding to main pipe (where appropriate).

Associativity between piping and structure (locations and penetrations) is generally not used (capability exists) due to complications when piping lines are deleted in the course of building new ship product models from hull structure and standard outfit packages.

Interference checking capabilities are limited to pipe-to-pipe and pipe-to-hull. Pipe-to-equipment interferences cannot currently be detected. Appropriate hull penetration locations and details are developed by the hull designers in discussion with the outfit designers.

The MATES system has been used for the development of some 40 ship designs. Consequently, MHI has a considerable inventory of ship designs in its 3-D CAD models. New products are generally developed from these CAD models. A high degree of topology is used to modify hull structure design. Standard equipment packages are also copied from library ship designs into the new product design model.

#### 5.5.4 PMS

Introduced in 1993 and not yet fully integrated with the MATES CAD/CAM system, the Production Management System (PMS) is used in the construction stage.

In detail planning, the location of every assembly block during the construction process is planned utilizing a space planning graphical display program. This program detects interferences in time and space during the planning phase. Physical size and locations of each block at any selected time are displayed on a plan view of the hall spaces. In a simultaneous display, the planned (black display) and actual (green display) dates each block will reside in the hall are indicated in a Gantt chart format. Blocks from multiple ship constructions are planned simultaneously with a color-coded display of the hall floor area utilized by each ship during each planning period (usually a day or two).

Conveyor movements are planned using a color-coded tact schedule planning program. The locations of subassemblies for each block are planned according to time needed at each major stage of construction. Labor resources assigned to each stage are adjusted according to the work content and available time at that stage. By the use of this interactive program, the sequencing of subassemblies through the major stages can be planned to level the workloads (to some extent) at each stage.

The planning and scheduling systems track welding lengths per day needed to achieve the scheduled work. Similarly, planned manhours versus actual expended manhours are tracked for cost control.

### 5.6 PLANNING AND CONTROL SYSTEMS

The production management system (PMS) was introduced in 1993. Schedules are prepared in three levels; long term, detail, and short term. The long term schedule provides the overall schedule, primarily concerned with grand assembly blocks, including their constituent blocks and erection schedules. The detail schedule addresses the specific facility and workforce (monthly) requirements to meet the overall schedule. Finally, short term (weekly) scheduling is done to determine the daily work tasks in each of the groups and facilities. Actual manhours expended and production progress are recorded daily and reported both weekly and monthly.

To assist in detail and short term planning, the MATES system provides the following formation about each assembly block to the PMS system:

- Ž Welding length
- Ž Weight
- ŽŽ ŽCenter of Gravity (detail planning only)
- Ž Number of parts
- Ž Number of pipes
- Ž Painted area (detail planning only)

The integration of the above MATES information with the PMS system was described as currently very weak. It is the focus of current development efforts at Nagasaki Shipyard.

## 5.7 CAD/CAM/CIM INTEGRATION

Nagasaki Shipyard utilizes abroad definition of CIM; that is, the integration of design, production planning, and production control. This is similar to the “computer integrated management” definition rather than the “computer integrated manufacturing” definition often more narrowly applied.

Following feasibility studies by the Shipbuilders Association of Japan and the Shipbuilding Research Association of Japan in the late 1980s, CIM projects by seven Japanese shipbuilders, universities, and the Ship & Ocean Foundation began in earnest in the early 1990s. Figure 5.10 illustrates the participants and organizational structure used to develop the concept (i.e. the frame model) for a shipbuilding general product model. The initial pilot model project concluded that an entity-relationship model in an object oriented database would be effective. Similarly, the use of expert systems would enable industry improvements in the labor-intensive shipbuilding industry. The history of the coordinated Japanese shipbuilding CIM projects is shown in Figure 5.11.

In March of 1994, a frame model specification was finalized by the Ship & Ocean Foundation to provide a product model generative object design document for the Japanese shipbuilding industry. This forms the foundation for MHI’s efforts to develop a General Product Model Environment (GPME) basis for accomplishing its CIM objectives. The fiwne model specification covers fifteen application systems:

- Ž General production management support
- Ž Design scheduling support
- Ž Basic design support

- Hull form design support
- Structural design support
- Outfitting specification and diagram design support
- Outfitting and machinery arrangement design support
- Machinery, piping, duct and cable design support
- Painting design support
- Numerical data processing
- Process planning support
- Quality control support
- Production scheduling support
- Dispatching and results gathering
- Delivery date and stock management support

The frame model covers class attributes and methods as well as associations between objects. These associations are essential for integration of information and necessary for continuous development of product model. The four major categories of the frame model are functional design (structural and outfitting), parts and intermediate products, production activity, and factory resources. Use of the last two categories permits a high degree of integration between design and production information.

Figure 5.1

# MHI Nagasaki Shipyard Main Plant

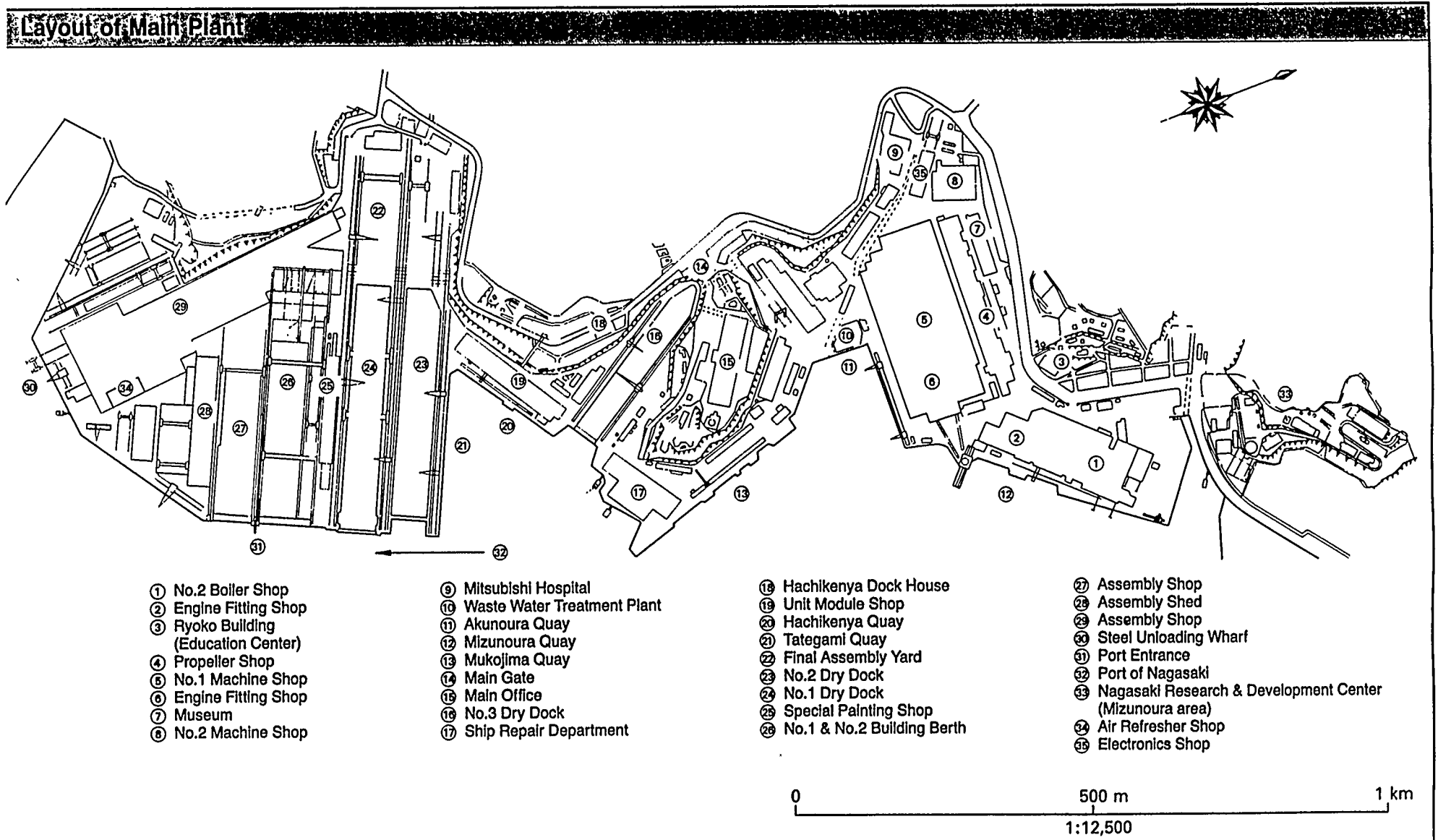


Figure 5.2

# MHI Nagasaki Shipyard Koyagi Plant

## Layout of Koyagi Plant

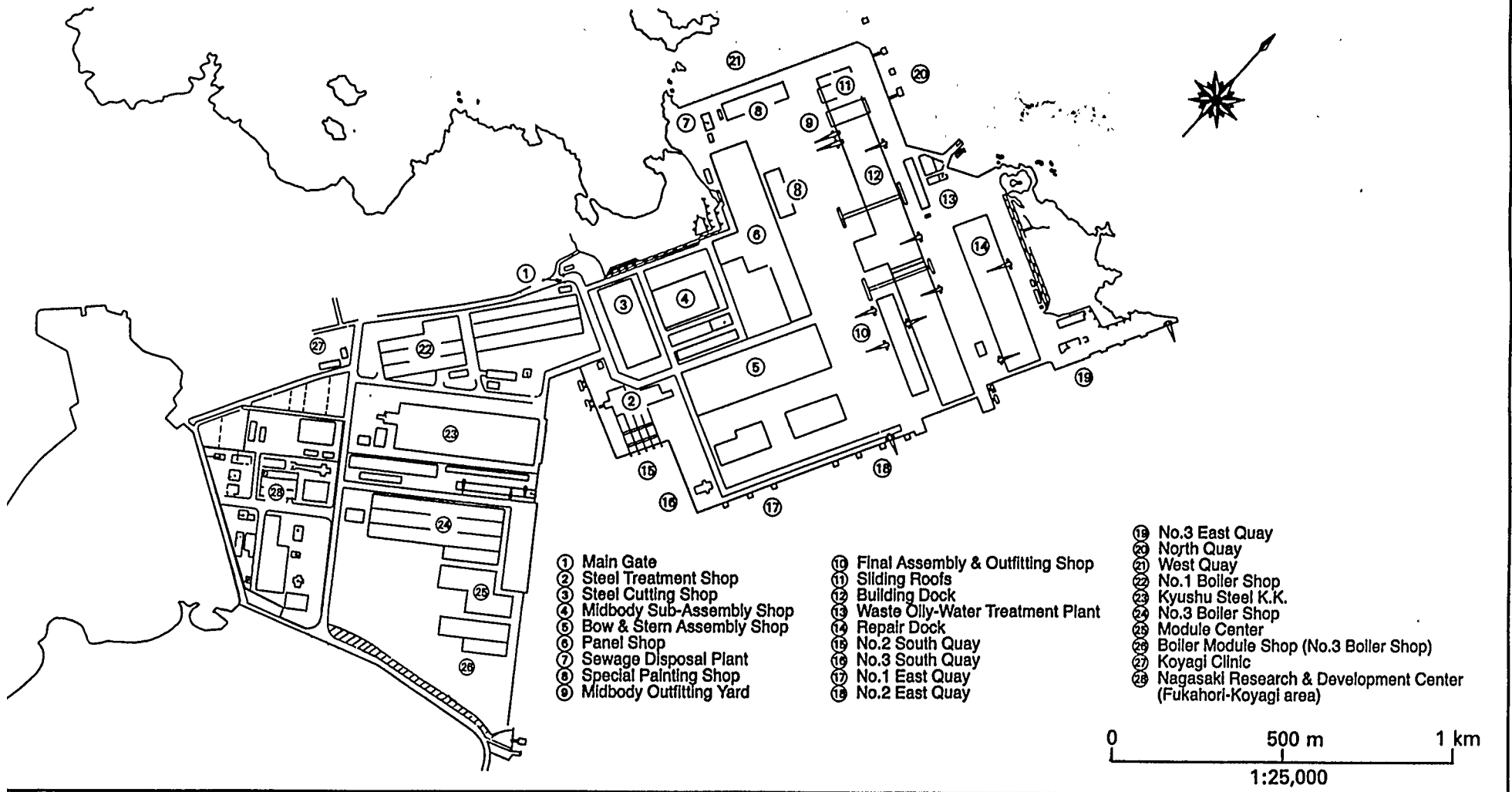
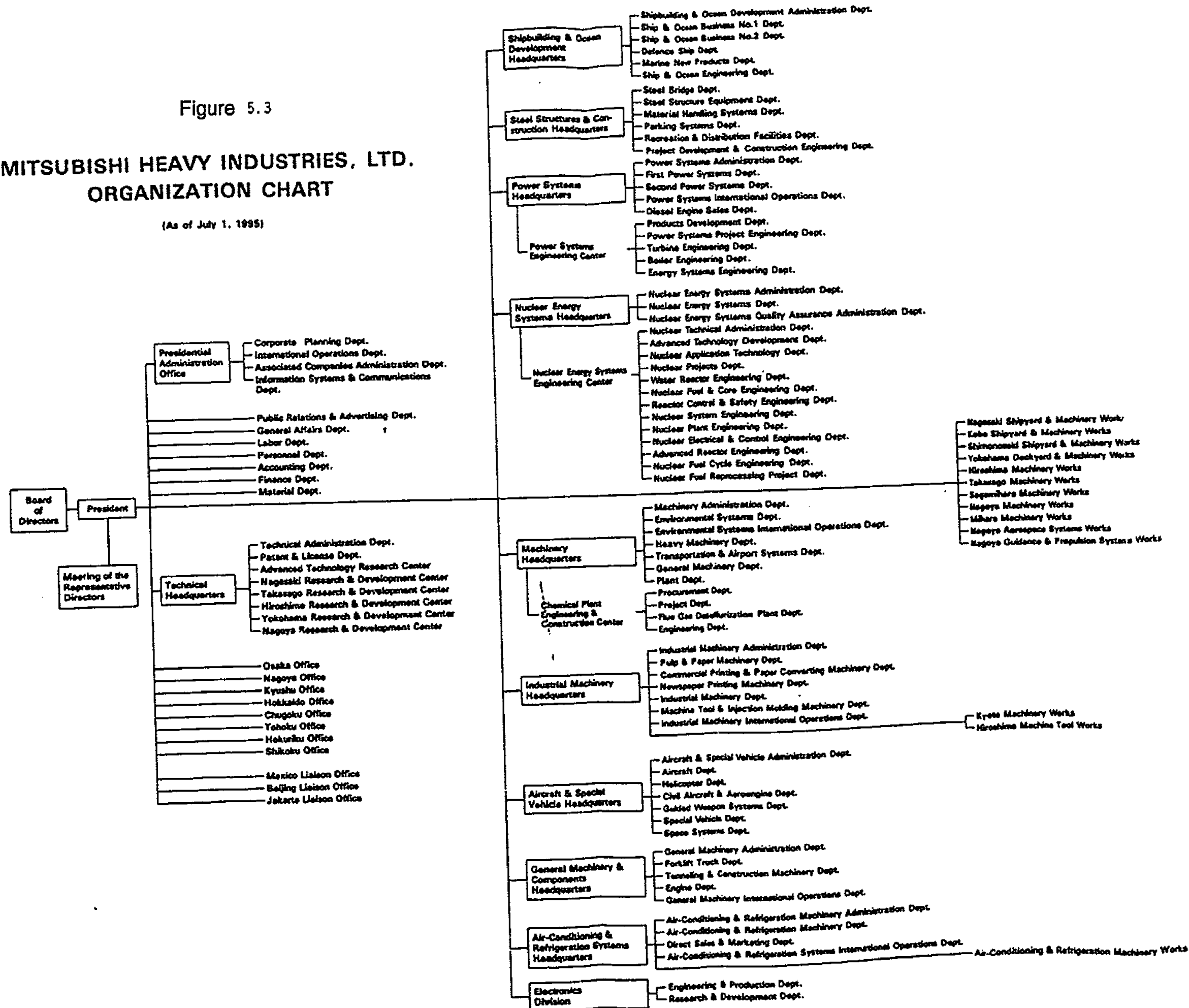


Figure 5.3

# MITSUBISHI HEAVY INDUSTRIES, LTD. ORGANIZATION CHART

(As of July 1, 1995)



# Image of the CIM for shipbuilding

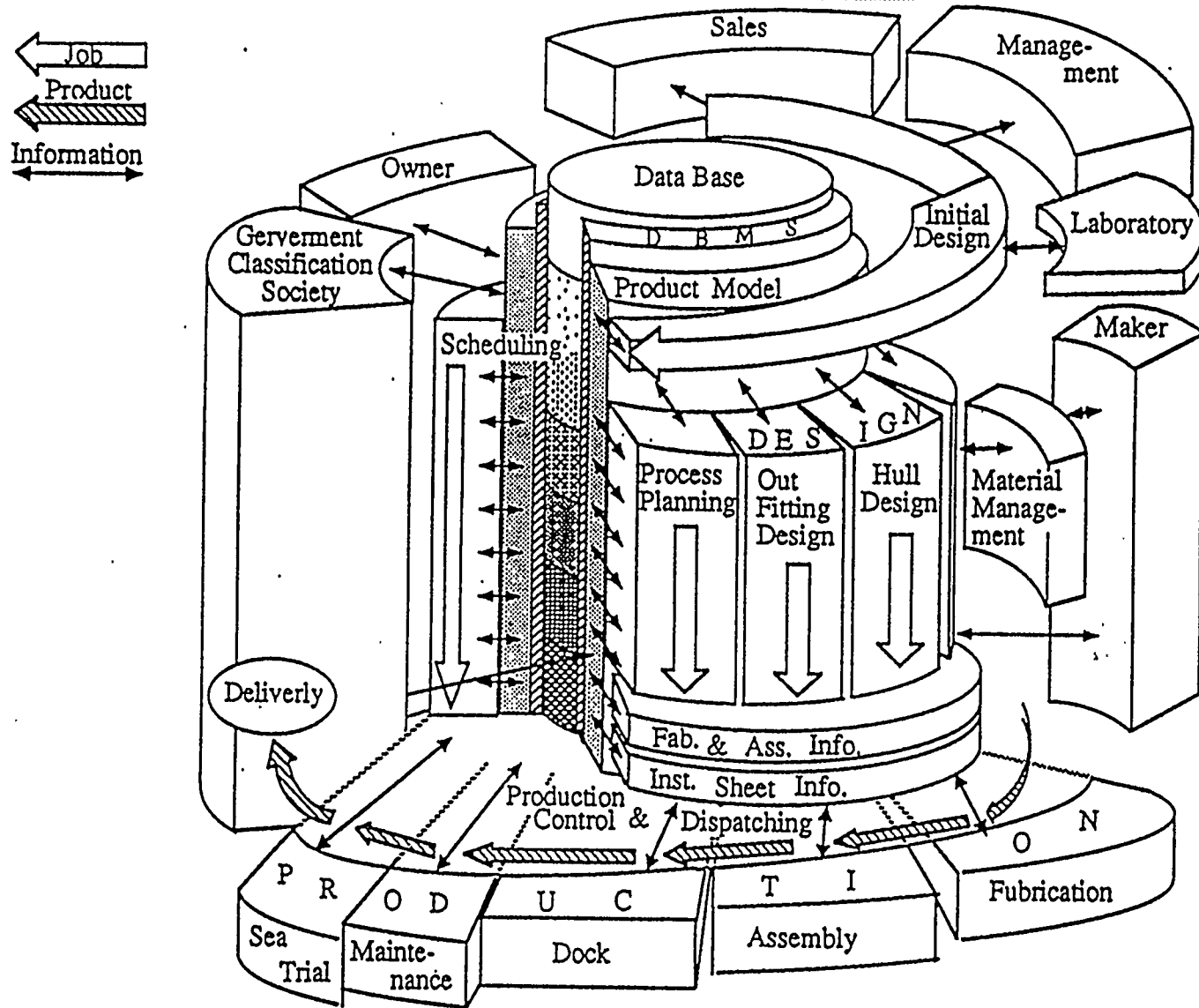


Figure 5.4

General Product Model Environment (GPME) Concept

Figure 5.5

Comparison of CIMs Between Shipbuilding and Automobile Industries

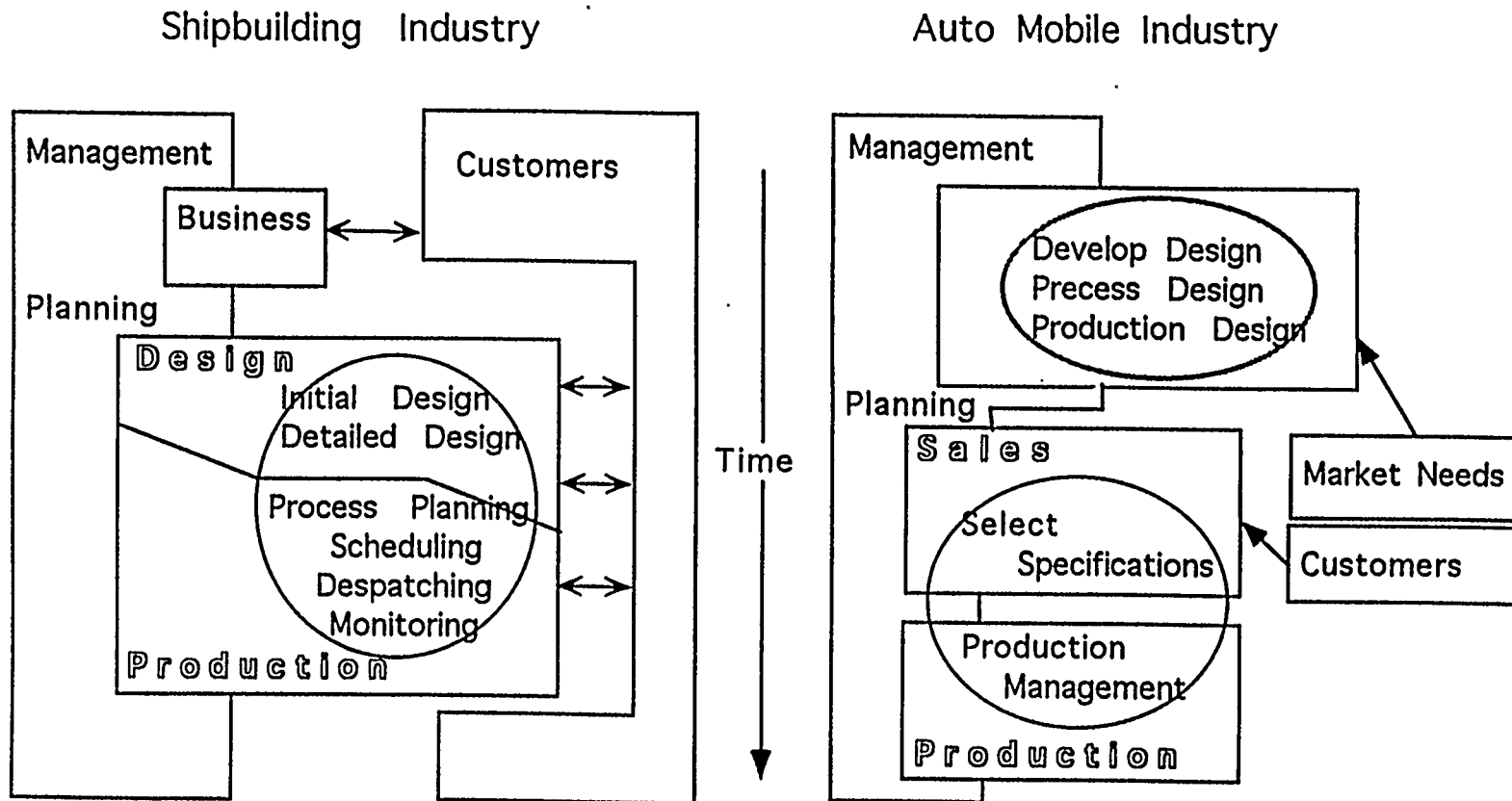
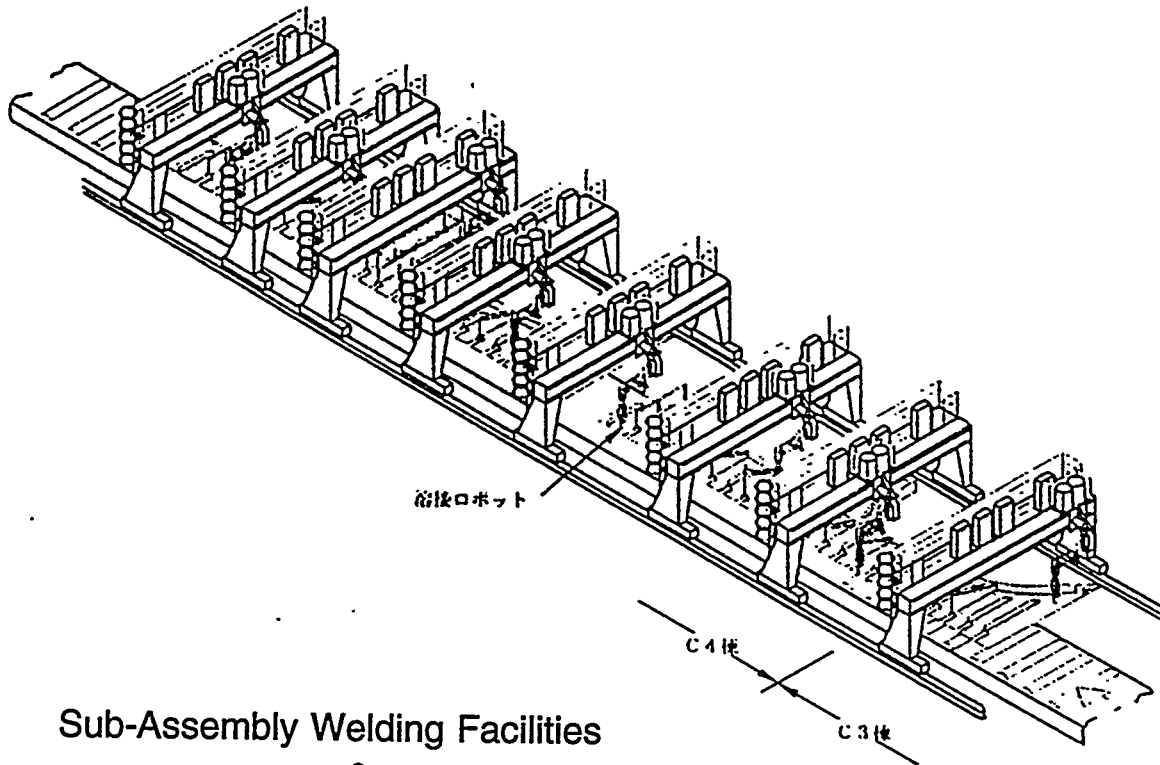


Figure 5.6

## Robotic Welding Facilities

### Stiffener Welding Facilities



### Sub-Assembly Welding Facilities

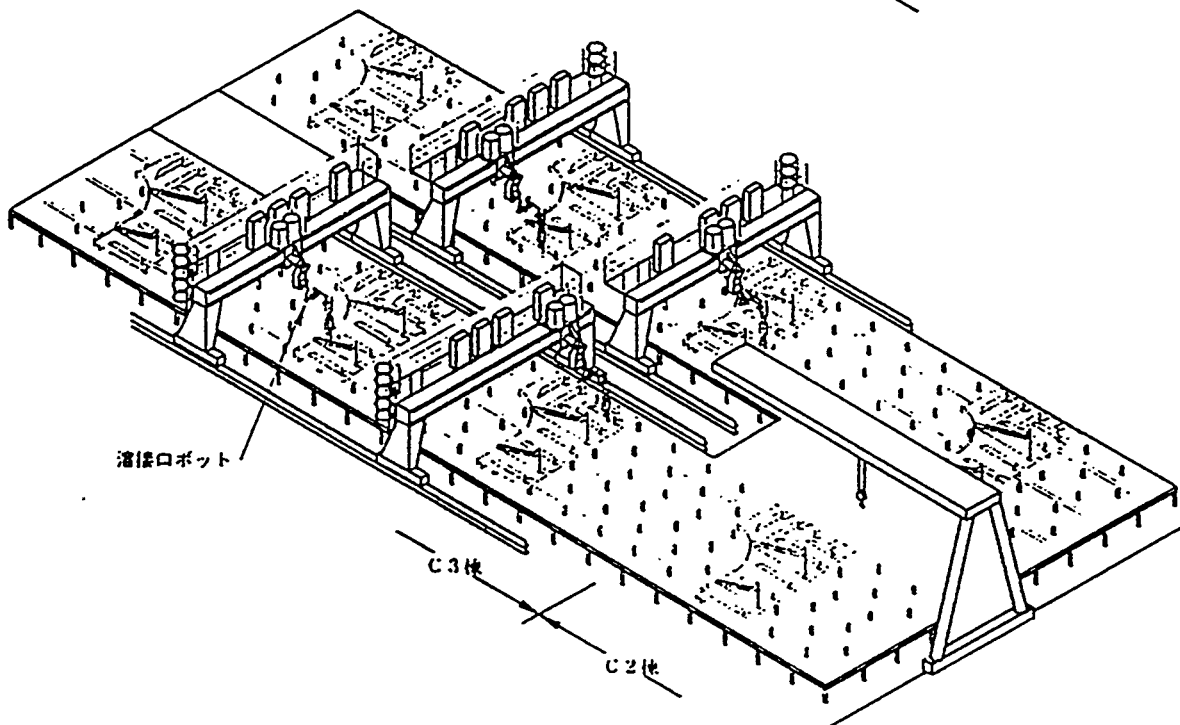
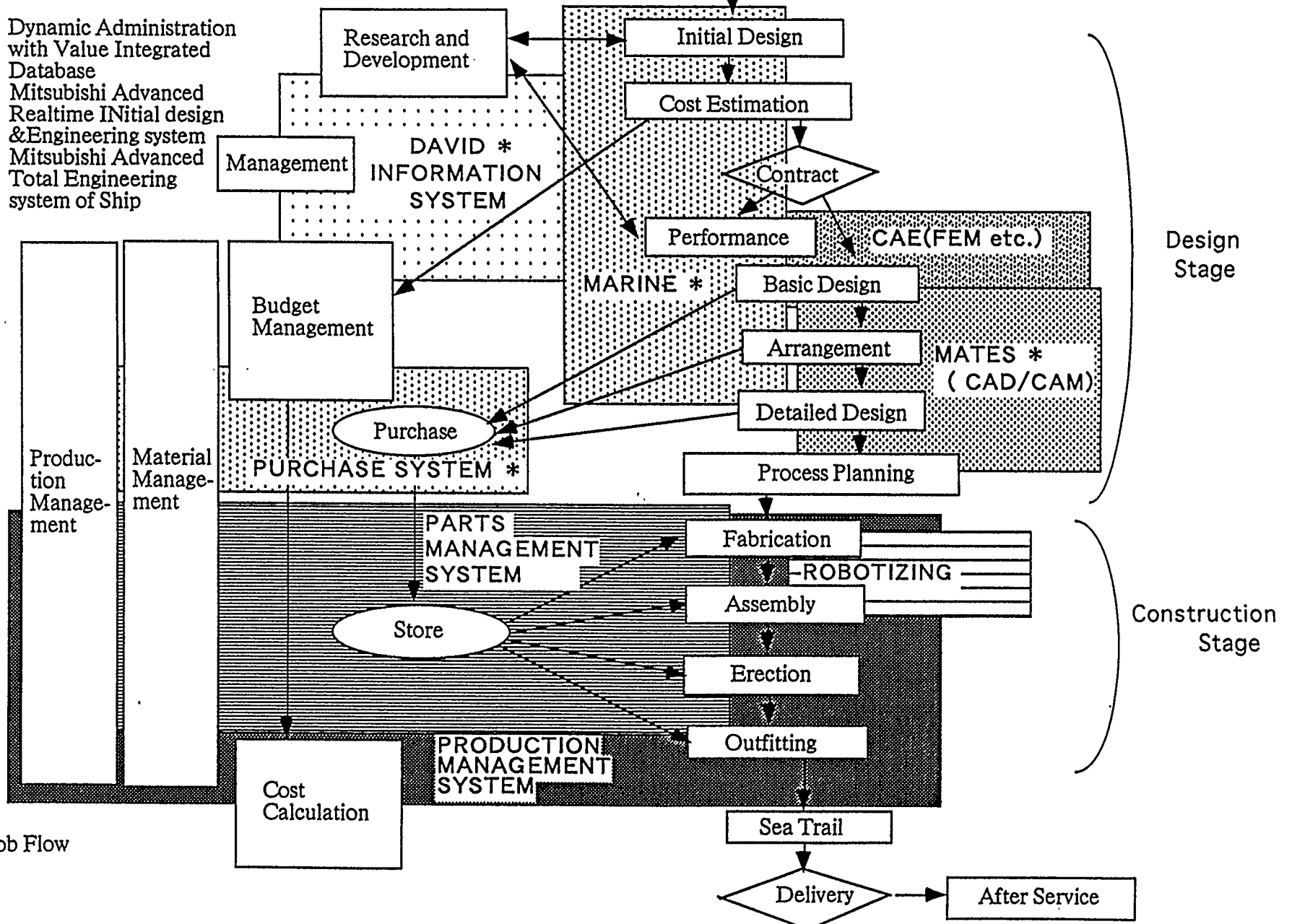


Figure 5.7

1995/10/20  
MHI Nagasaki

MHI CIM (Present)

DAVID: Dynamic Administration  
with Value Integrated  
Database  
MARINE: Mitsubishi Advanced  
Realtime Initial design  
& Engineering system  
MATES: Mitsubishi Advanced  
Total Engineering  
system of Ship



## Structural Patterns in MATES Hull System



## Transverse Frame Changes Using MATES

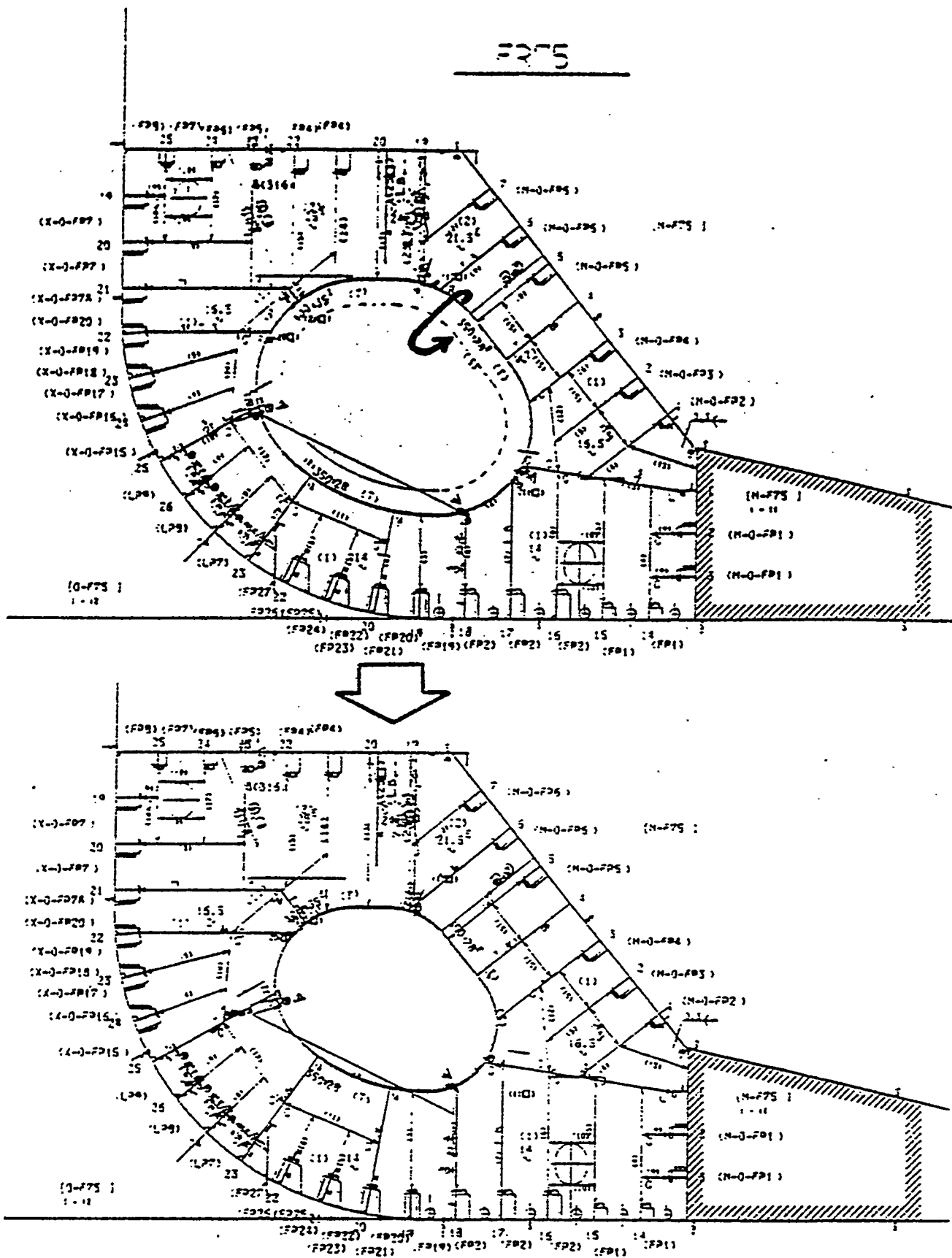


Figure 5.10

## Organization of Frame-Model Project

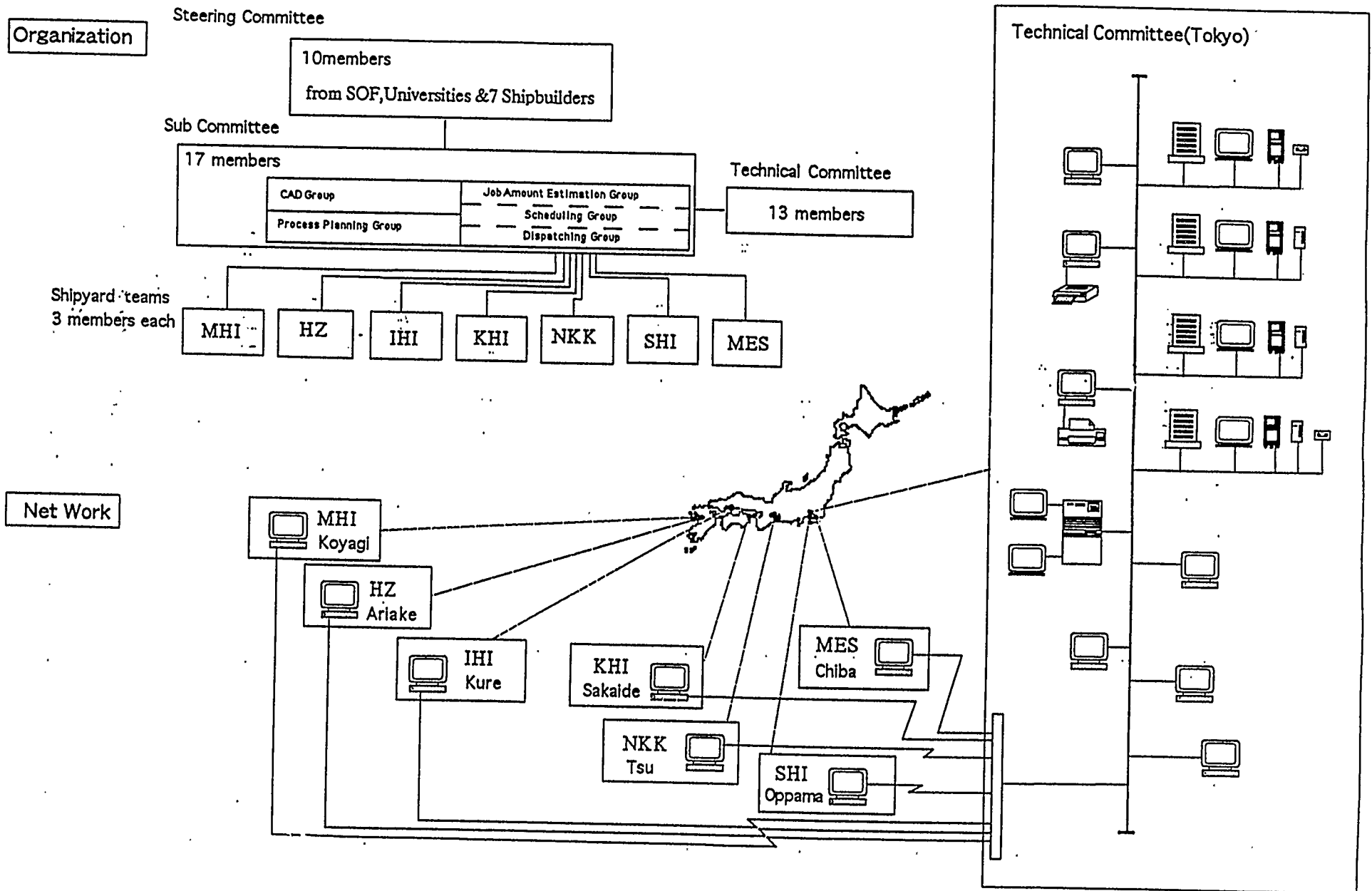
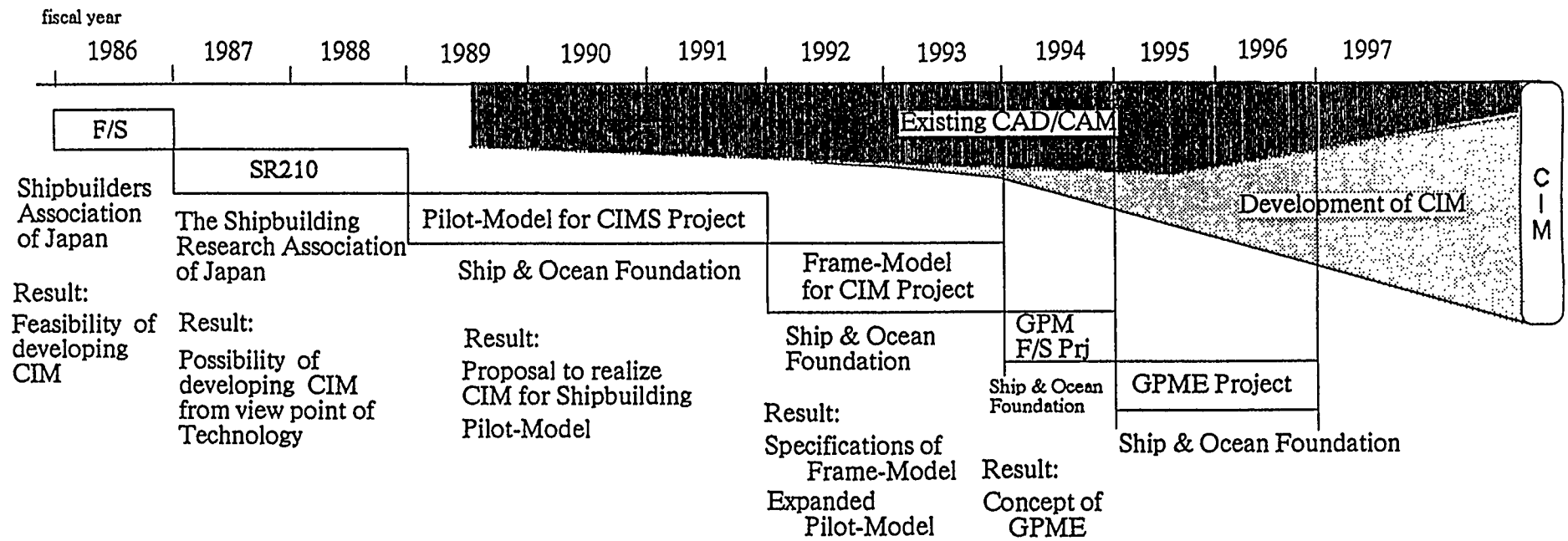


Figure 5.11

# The History of the CIM Projects by 7 Shipbuilders



## 6.0 HITACHI ZOSEN

### 6.1 ARIAKE SHIPYARD OVERVIEW

The Ariake yard was opened in 1973. During the shipbuilding business turndown in the 1970s, Hitachi Zosen agreed (along with other Japanese shipyards) to utilizing only 65 percent of yard capacity for shipbuilding. The non-shipbuilding capacity is used for offshore products, including jackets and semisubmersibles. Most of the ongoing work seen during our visit appeared to be focused on single hull (domestic use) and double hull VLCCS, and a large oil storage vessel. The fifth and final storage vessel was being completed as part of a national project. Shipbuilding capacity was suggested to be about four VLCCS per year.

The VLCC products were characterized as containing 300,000 pieces, 95 percent of which are completely assembled in blocks prior to block assembly in the drydock. A brief view of the main outfitting hall confirmed a very high level of outfitting on the blocks. About 90 percent of the welding was said to be done indoors in the construction halls. Shipbuilding costs for these VLCCS were described as 60 percent material, 25 percent labor, and 15 percent design/overhead.

The Ariake works is Hitachi Zosen's largest and most modern shipyard. It occupies about 1.5 million square meters (about 373 acres) and includes two large drydocks, each serviced by a 700-ton gantry crane. The layout of the yard is illustrated in Figures 6.1(A) and 6.1 (B). In addition to shipbuilding and repair, the Ariake works produces offshore structures (jackets, semisubmersibles, etc.) and large vessels and heat exchangers for the process industries.

The 1530 person workforce at Ariake consists of direct HZ employees, subsidiary company employees, and subcontractors. The breakdown is as follows:

	<u>Direct</u>	<u>Subsidiary</u>	<u>Subcontractor</u>
General Affairs	25	3	
Quality Assurance	17	1	
Ship Design	71	88	
Shipbuilding	453	276	573
Oil Storage Ship Proj.	5	1	
Production Tech. Dev.	10	1	
Safety	5		
TOTALS:	<u>586</u>	<u>370</u>	<u>573</u>

The subsidiary company organization was created to flatten the organizational structure and create more flexibility for changing products and workloads. Sub-contractors are used for much of the fitting, welding, and painting work, both in the assembly areas and shipboard.

Much of the welding was described as gas metal arc using flux core consumables and a CO<sub>2</sub> shielding gas.

## **6.2 BUSINESS STRATEGY**

The Ariake Works is well equipped to build a variety of large vessels efficiently; VLCCs, ore carriers, container ships, etc. Large drydock and crane facilities, and automated steel production facilities, including portable robotic welders, are conducive to high rates of steel production.

Hitachi Zosen views design activities as having three phases; basic, detail, and production. Basic design addresses arrangements, midship sections, and construction profile. Detail design addresses structural member arrangements and welding details. Production design deals with development of production support information, such as parts lists, drawings, and NC cutting data.

## **6.3 COMPETITIVE STRATEGIES**

### **6.3.1 Production Practices**

The Ariake shipyard utilizes many “best practices” to minimize costs. Complete designs, careful attention to production planning, preoutfitting, factory automation, just-in-time procurement accuracy control, and flexible labor resources all contribute to low cost shipbuilding. Hitachi Zosen has been a leader in the use of robots and other automated approaches in cutting, marking, and welding for maximum productivity. Rework is minimized by a number of methods; accuracy control and process automation being the most evident. Low hydrogen consumables, high quality steel, and slow weld rates are also used to minimize pitting due to out-gassing. Other practices, such as use of cherry pickers in place of scaffolding, are used to minimize painting rework.

Advanced high productivity welding processes are also being implemented. An automated FCUB one-sided welding process for plate joining was introduced in 1992 that is about 2.5 times faster than conventional FCUB processes.

### **6.3.2 Factory Automation**

Hitachi Zosen has been a leader in shipbuilding automation. Since the early 1980s, the Ariake Works has been applying automated welding technology to shipbuilding. These developments include the use of simple gravity and semiautomatic welding devices, portable robotic welding units, and overhead gantry robotic welding workstation facilities. The extent to which automation is achieved was described as the true measure of shipyard productivity.

Design office automation is currently the subject of further automation efforts intended to reduce schedule and costs. These efforts focus on automating access and flow of information, both internally and with vendors and suppliers.

### **6.3.3 CAD/CAM**

Since the 1960s, Hitachi Zosen has been a leader in the development and application of computer technology to shipbuilding. Originally not much more than an automated drafting system, the Hitachi CAD/CAM technology has developed into HICADEC'S current 3-D geometry modeling capabilities. This remains the cornerstone of current design tools and is expected to become highly integrated in evolving product model-based CIM systems.

### **6.3.4 Product Model-based Engineering**

The HICADEC CAD/CAM system currently provides for detail design and most of production design to be accomplished in seven to eight months between completion of the basic design and first cutting of steel. The production planning (block divisions and fabrication sequence planning) is done independently. A new product model system, Product model Hicadec (PHI) is being developed that is expected to reduce this design time to four to five months and integrate product information with the production planning efforts.

An effective product model-based system is expected to provide production engineers with access to 3-D CAD data early enough in the design process to permit evaluation of design changes based on production considerations. An object-oriented database (OODB) approach to product modeling will enable effective integration with production planning very early in the design process. Artificial intelligence (AI) methods are expected to be developed and employed to support production process planning.

### **6.3.5 Computer-Integrated Management (CIM)**

Computer-integrated management (CIM) capabilities are still under development at the Ariake Works. The objectives of these development efforts are improved

production automation and optimum production planning and total management. These objectives require early development of product information, applications of robots and automated machines, and enhanced communication of product information, especially between design and production. The Hitachi Zosen CIM concept is illustrated in Figure 6.2.

#### 6.3.6 Performance-Based Labor Compensation

Worker payments are made for work task completions rather than for hours spent on tasks. The design office determines the work content for tasks and monitors actual production records to keep the work content assessments accurate. Each worker is typically assigned to several job tasks on each day. Next day assignments are predicated on the status tasks completed or in progress from the previous day. One obvious concern is the quality of tasks completed. Task completion must be defined in terms of required quality (e.g. dimensional accuracy, weld quality) or this type of system can be counterproductive.

### 6.4 AUTOMATION

#### 6.4.1 Robotic Cutting and Welding

Initial robotic welding efforts used portable multiarticulated NC robots known as HIROBO WR-L50. These are still in use today primarily for “egg crate” hull constructions. Twin-torch-gantry-mounted NC robots were introduced in 1988 to weld stiffeners on web plates. They utilize infrared sensors and touch registration for accurate positioning relative to the CAD product model description. Touch is sensed when voltage through the weld wire is initiated.

Portable self-driving 3-axis robots were introduced for multipass single-sided block joint welding in 1990. These robots, known as HIAUTO, are track-guided and utilize special root gap adaptive control functions to compensate for variations in root gap. Despite the adaptive control features, HIAUTO requires reasonably good accuracy (gaps, alignment) at the joint. Ariake experience suggests that accuracy control rather than adaptive control is easier in achieving quality and production objectives. Laser measuring is used to measure gaps; those over 3 mm are excluded from robotic welding and completed by follow-up manual welding.

In 1992, a 20-torch line welder was introduced for simultaneous welding of up to ten longitudinal frames on a skin plate. Brief descriptions of many of the robotic and automated welding facilities used at the Ariake Works are included in Appendix D.

Current development efforts are directed towards extending robotic welding from flat plate assemblies typical of the parallel innerbody to curved assemblies typical of the fore and aft sections. Initial efforts are to develop the HICURVE system for welding curved longitudinal to skin plating. HICURVE is a self-driving portable robotic welder with sensors used to detect the fitting angles and joint inclinations. Adaptive control is used to adjust the torch angle and wire aiming point based on these sensor indications. Appropriate welding parameters are also selected from a library in the robot-controller based on these indications.

The ultimate automation for shipbuilding at the Ariake Works was described as 29 percent robotic, 32 percent other automatic, 30 percent semiautomatic, and 9 percent gravity. Flexibility in the robotic welders is emphasized in order to achieve both agile manufacturing and maximum use of needed humanware objectives. This emphasis suggests continued reliance on workforce skills and innovative approaches.

Accuracy control plays an important role in Hitachi Zosen's approach to factory automation. NC plasma cutters, CAD-integrated laser measurement systems, weld shrinkage compensation, and a number of in-process error correction procedures are used to achieve dimensional tolerances. Typically, two to three mm excess plate material (length or width dimension) is supplied to account for weld shrinkages. These approaches enable transverse plates to be joined (butt welded) and cutouts for longitudinal cut by NC cutters prior to being attached to hull plating with stiffeners already attached. At this point, accurate measurements of cutout locations (and sizes) are taken and compared with CAD model data to determine fitup interferences. Recuts are selected when necessary based on maintaining a  $\pm 1$  mm tolerance in plate positioning, and minimizing the number of required recuts. A typical number of required recuts was indicated to be three to four per block.

A number of welding process parameters are controlled by the welding automation in order to maintain good weld quality with a minimum of rework. Low hydrogen consumables, slow weld head speed (to boil out primer before fusion), and high frequency (6-7 Hz) weaving (to help outgassing) are all employed.

#### 6.4.2 Painting Automation

Painting automation efforts were initiated in 1991. The objectives of these efforts were to save paint costs, stabilize the paint quality, and improve the environmental impact of painting. A  $\pm 2$  micron tolerance on the 17 micron preconstruction primer (inorganic zinc) is sought in order to maintain good weld quality without having to remove primer or otherwise prepare the surface for welding. Painting automation was suggested to be a necessity for future commercial shipbuilding.

The automation efforts could be grouped into three areas; robotic placer/manipulator with 6-axis motions, interface with 3-D CAD product model (surface data rather than line data needed for welding), and process issues, such as explosion countermeasures and paint supply (mixers, heaters, delivery hose that avoids damage to already painted surfaces, etc.). The approach being developed for the CAD interface is similar to the CAMEX welding approach described in Section 6.5.4. The key elements are IGES data transfer from the HICADEC CAD model, paint libraries (type of paint, number and thickness of coats), and NC data generation for the required robotic motions.

#### 6.4.3 Design Office

Productivity studies have been made that suggest only 30 percent of the efforts are concerned with actual design work. The remaining 70 percent are directed towards;

- production of documents,
- searches for information,
- inquiries,
- **communications**, and
- miscellaneous.

Three directions are being pursued to improve office automation. End-user computing, in which each person utilizes a PC for applications such as e-mail, MS-WORD wordprocessing, or AutoCAD graphics are being stressed. Hitachi Zosen indicated that this is an area in which the U.S. is well ahead of the Ariake Works.

Common use information approaches are being addressed to reduce the use of paper and further streamline communications. Design databases, document management systems, network access to AutoCAD and MS-WORD files, and raster images of annotated documents are being explored. Finally, faster inquiry systems and methods are being developed for vendor communications. Initially, PC to PC (paperless) FAX methods are expected to facilitate exchange of inquiry specs, quotations, and eventually purchase order specs. Longer term, electronic data interchange (EDI) methods are expected to replace the FAX modem communication methods.

Increased utilization of 3-D product model data from vendors does not seem to be planned. Problems with too many CALS approaches being considered and developed seem to preclude the kind of standardization that will be required for effective use of vendor 3-D product model information. The analogy of the successful use of vendor information in the automotive industry was discussed. Many of the vendors/suppliers serving the automotive industry are dedicated to that single industry. Standardization of systems amongst users and suppliers is a viable approach to effective data exchange. The shipbuilding vendors and suppliers, however, tend to serve multiple industries, which precludes their selection of systems to serve the needs of only their shipbuilding customers.

## 6.5 MAJOR CAD/CAM/CIM SYSTEMS

The BMT software has been used by Hitachi Zosen for Naval Architecture (NA) calculations. A more integrated Initial Design Integration System (IDIS) is currently being developed around an Oracle database (see Figure 6.3). Little description of this system was provided. The NA calculations are performed using application programs that access the Oracle database.

### 6.5.1 HICADEC CAD/CAM System

The initial CAD system, called HIZAC, was introduced in the 1960s. A database-oriented second generation system was introduced in the mid 1970s. In 1981, Hitachi Zosen started development of the 3-D HICADEC CAD/CAM system. This system was introduced within Hitachi in the mid 1980s. HICADEC consists of four functionally independent subsystems; hull, arrangement, piping, and electric. Each subsystem is comprised of various functional modules that are self-contained software packages for ease of maintenance and future system enhancements. The hull and piping subsystems utilize different data structures that preclude access to combined data. GRADE/G is the primary graphic data processing system supporting each of the application subsystems.

Appendix F contains a 1989 paper authored by Hitachi Zosen planning and design personnel, which describes the HICADEC system.

### 6.5.2 PHI Product Model System

Traditional CAD/CAM databases, including HICADECs, do not contain sufficient information to support production planning and management. Likewise, the HICADEC subsystems (e.g. hull and piping) and the production planning systems cannot currently exchange 3-D CAD data. The Product model by Hitachi zosen (PHI) system concept was developed to overcome these limitations by providing a common object-oriented database (OODB) with interfaces to HICADEC-H and HICADEC-P as well as to production planning/management systems. The PHI systems also automates the decomposition of each block into its component subassemblies. A brief system overview of PHI is illustrated in Figure 6.4.

PHI development started in 1993. It has been developed in the C++ programming language utilizing ObjectStore, commercially available object-oriented database (OODB) software. The graphics representations are B-reps of polygons utilizing a Hitachi Zosen display program (WEED) based on a commercially available graphics library (HOOPS). The B-rep polygon approach was selected as a compromise between the accuracy and performance measured by display speed and data storage volume requirements. The software runs on Sun SPARC1 O workstations.

Data version control between HICADEC and PHI is essential for consistency. This has been accomplished for HICADEC-H by use of a log file. HICADEC-P does not provide a log file or other means of version control for maintaining consistency with the data in PHI.

A process planning expert system in PHI is being developed. This system currently has about 250 rules that guide the selection of production decisions based on available facilities and welding line length by welding position.

#### 6.5.3 Production Planning/Management Systems

A variety of systems are being developed and implemented, all utilizing access to the OODB database in the PHI product modeling system. The overall system design is illustrated in Figure 6.5. Some of the acronyms used in this Figure for applications software packages are briefly described in Figure 6.6. Further information on some of these applications is included in Appendix E.

#### 6.5.4 CAMEX Welding Robot NC Data

The CAMEX program is used on PC hardware by the shop foreman to develop welding robot NC data from CAD model data in the HICADEC system. Appropriate CAD data for an assembly are first downloaded from HICADEC-H via IGES file format over the shipyard Ethernet LAN system. Each weld line to complete the assembly is identified by CAMEX and numbered sequentially. The assembly geometry is displayed using an AutoCAD system that also indicates weld types and leg sizes for each weld line. The structure and/or weld line data may be edited if necessary for completeness and accuracy. The foreman selects appropriate NC programs for each weld line from a library of previously developed routines. CAMEX then checks the use of the selected NC routine for interferences with the structural assembly. Once suitable NC programs are selected through interactive use of the software, the program identification (number) is assigned to each weld line and marked with chalk on the actual parts. Those weld lines that cannot be welded by the robotic welder (due to interference or reach limitations) using an NC routine are marked for subsequent manual welding. In the example demonstrated, 81 weld lines required 41 different NC program routines. Only one or two of these weld lines could not be performed by the robotic welding equipment.

The implementation of CAMEX appears to be based on the use of wire-frame AutoCAD representations and the use of 5-axis robotics. It is therefore limited in application to those assemblies comprised of straight lines and simple arcs. By comparison, state-of-the-art systems being developed today (e.g. PAWS and Cybo Robotics) are based on the use of true solids modeling. The mathematical rigor in these approaches provides for applications involving general curved surfaces. An advanced system is currently being developed in support of the HICURVE robotic welding system.

Much of the numerical methodology used in CAMEX, including use of Freeman's chain and Dijkstra's method, was reported in the 1994 ICCAS Conference proceedings [Brodda, 1994]?

## **6.6 PLANNING & CONTROL SYSTEMS**

Sections 6.3 and 6.5 have introduced Hitachi's approach to Planning& Control. Many of the existing capabilities use functions and data of HICADEC. Hitachi's direction for Mure implementation is based on experience gained in the Japanese CIM study. References 2, 3, and 4 provide general background for the approach developed through the CIM research efforts.

Principal parts of the approach relate to defining the sequence and detailed information about the product during the design. Figure 6.5 shows NEED, JIG, TOPOS (LASC) and LIPSS, which are being developed and used for design interaction. Figure 6.6 provides the acronym description and Appendix D provides an illustration for the interactive graphics tool for each application. CAPP, HIMEST, HICAP, HIFACT and HICASP were not discussed or demonstrated in detail. The description in Figure 6.6 indicates that these applications relate specifically to planning and control for schedule and capacity considerations (see references cited for further information).

NEED is a program that combines the product model geometry with build strategy rules to define and display the assembly network and assembly sequence of groupings of parts. There are some 250 rules implemented in the application that can create and display an assembly network and sequence with 80-90 percent consistent and correct information being automatically generated. The data come to HICADEC through PHI for either previous or current designs. Viewing of the assemblies can be user controlled in a display window and the network can be modified in its GUI window as the detail design is finalized.

JIG is an application used to check the orientation of curved shell assembly in the planned building position. The inclination of the assembly can be changed. HICADEC provides output automatically to support production once the orientation of the assembly is determined.

LIPSS allows the designer and planner to simulate the lifting of assemblies and to arrange the lifting pads considering standard crane rigging components, such as spreader beams, fixed and variable length cables, etc. The simulation can handle turn-over and tail-off operations and provides continuous monitoring of block forces and motion of the center of gravity of the assembly.

TOPOS and LASC provide graphical input and viewing to plan automated painting or spraying. TOPOS provides the viewing of the assembly to be coated and the definition of the coating by surface. LASC provides the analysis of the spray created by nozzles placed in 3D space. LASC can be combined with paint robot planning or used to check the cleaning effectiveness of tank cleaning arrangements.

In all applications, PHI provides a consistent set of information for viewing of the product model and to record the process information needed by the application.

## **6.7 CAD/CAM/CIM INTEGRATION**

Similar to MHI, Hitachi's definition of CIM is the broader computer-integrated management rather than the computer-integrated manufacturing definition. The goal of current Hitachi Zosen (HZ) efforts is to integrate the graphical (CAD) data with the management data required for production planning and management. Object-oriented database (OODB) approaches are being used with the intent of developing more expert systems to facilitate the development of designs consistent with producibility considerations. One concern HZ mentioned about this approach is the rather small size of OODB vendors and the inherent risks of survival and that OODB product developments may not keep pace with HZ needs.

Improved methods to facilitate product model development, such as expert systems, topological product modeling, and component libraries, are needed so that production can base planning on product model data rather than on assumptions based on their experience.

Figure 6.1a

## HZ Ariake Works (Layout)

### ■ Brief History

- March 1973 Commenced operation of Ariake Works.
- October 1974 Completed construction of Ariake Works.
- December 1974 Delivered the first ship, "SHUNKO MARU".
- August 1977 Delivered the world's largest class 500,000-ton tanker, "ESSO ATLANTIC".
- June 1980 Started the building of offshore structures (rigs).
- May 1980 Completed construction of land-use equipment shop.
- January 1982 Delivered the world's largest ore carrier.
- October 1985 Completed construction of arctic semi-submersible oil drilling rig.
- June 1986 Completed construction of the world's largest class jack-up type oil drilling rig.

### ■ Major Products

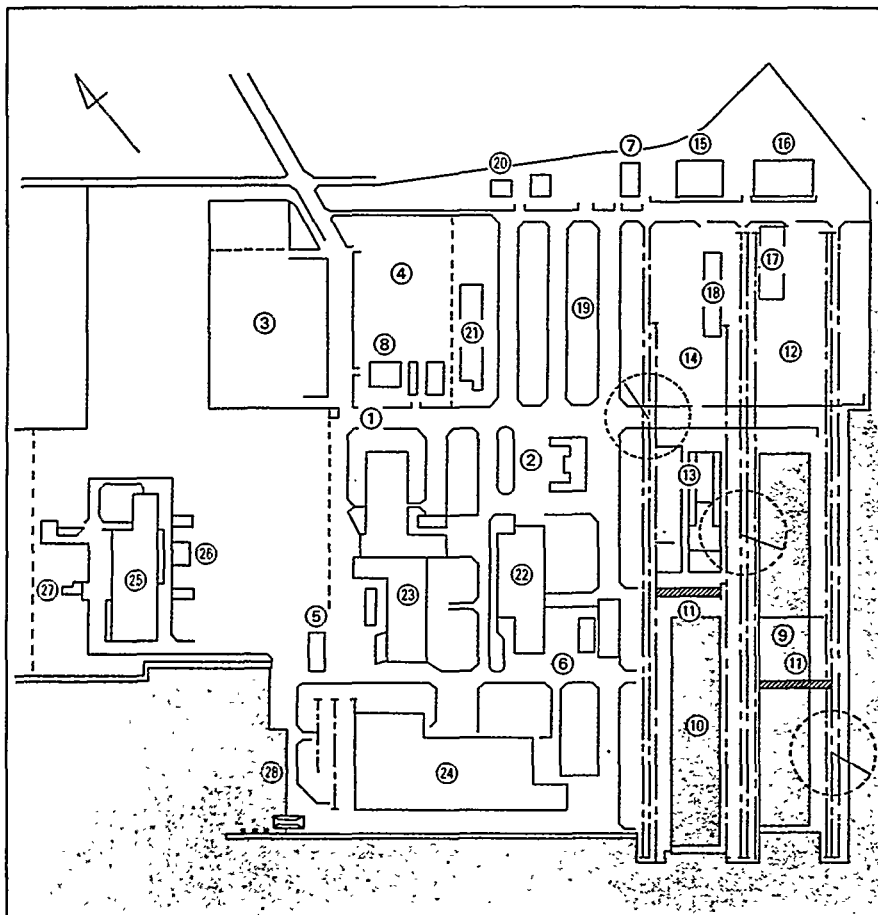
- **Ships (construction, conversions and repairs)**  
Tankers, ore carriers, bulk carriers, container ships, other commercial carriers and passenger ships.

- **Offshore Structures**  
Oil drilling rigs, oil production platform jackets, oil production platforms, floating docks, plant barges, floating breakwaters, floating pontoons for mooring.

- **Plants**  
High-temperature and high-pressure reactors, pressure vessels, storage tanks, rectifying columns, heat exchangers, evaporators, mixing vessels, and other large and heavy vessel structures.

- **Other Products**  
Multi-story parking garages and other mechanical systems.

### ■ Layout of Ariake Work



- ① Main Gate
- ② Main Office
- ③ Parking Area
- ④ Playing Field
- ⑤ No. 1 House
- ⑥ No. 2 House
- ⑦ No. 3 House
- ⑧ Gymnasium
- ⑨ No. 1 Building Dock
- ⑩ No. 2 Building Dock
- ⑪ 700-ton Gantry Crane
- ⑫ No. 1 Section Joining Yard
- ⑬ No. 2 Section Joining Yard
- ⑭ No. 3 Section Joining Yard
- ⑮ Pipe Shop
- ⑯ Warehouse
- ⑰ Deck Outfitting Shop
- ⑱ Outfit Module Shop
- ⑲ Block Outfitting Shop
- ⑳ Power Plant
- ㉑ Paint Shop
- ㉒ Fabrication Hall
- ㉓ Panel Shop
- ㉔ Prefabrication Shop
- ㉕ Pressure Vessel Work Shop
- ㉖ Heat Treatment Furnace
- ㉗ Radiograph Inspection Room
- ㉘ Steel Unloading Pier

### ■ Annual Production Capacity

Shipbuilding	800,000 gross tons
Ship repairs and conversions	5,450,000 gross tons
Steel works in weight	150,000 tons
Land-use equipment	18,000 tons

### ■ Docks

Name	Dimensions	Length (m)	Width (m)	Depth (m)
No. 1		620.0	85.0	14.0
No. 2		380.0	85.0	14.0

Figure 6.1b

HZ Ariake Works (Aerial View)

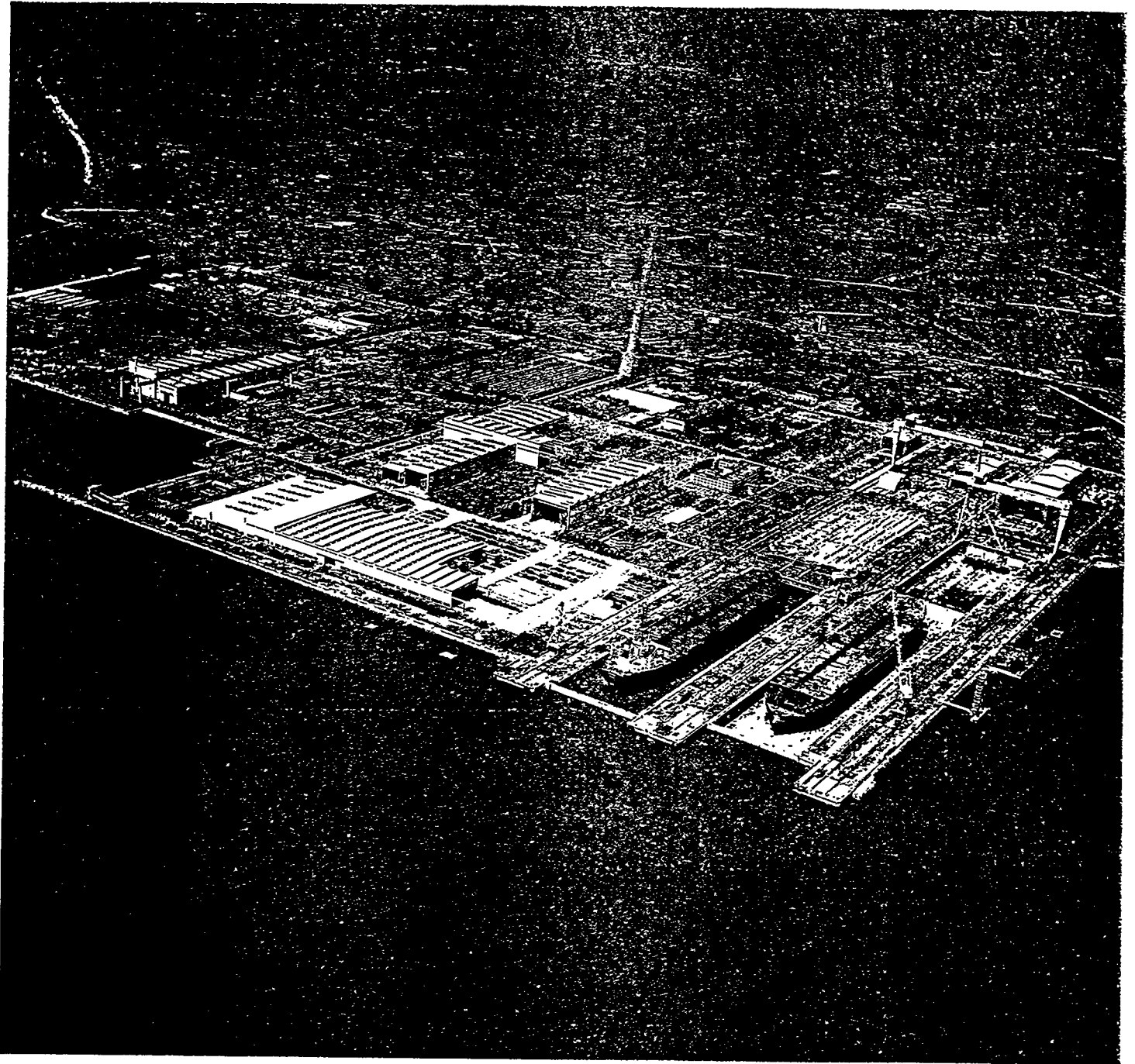
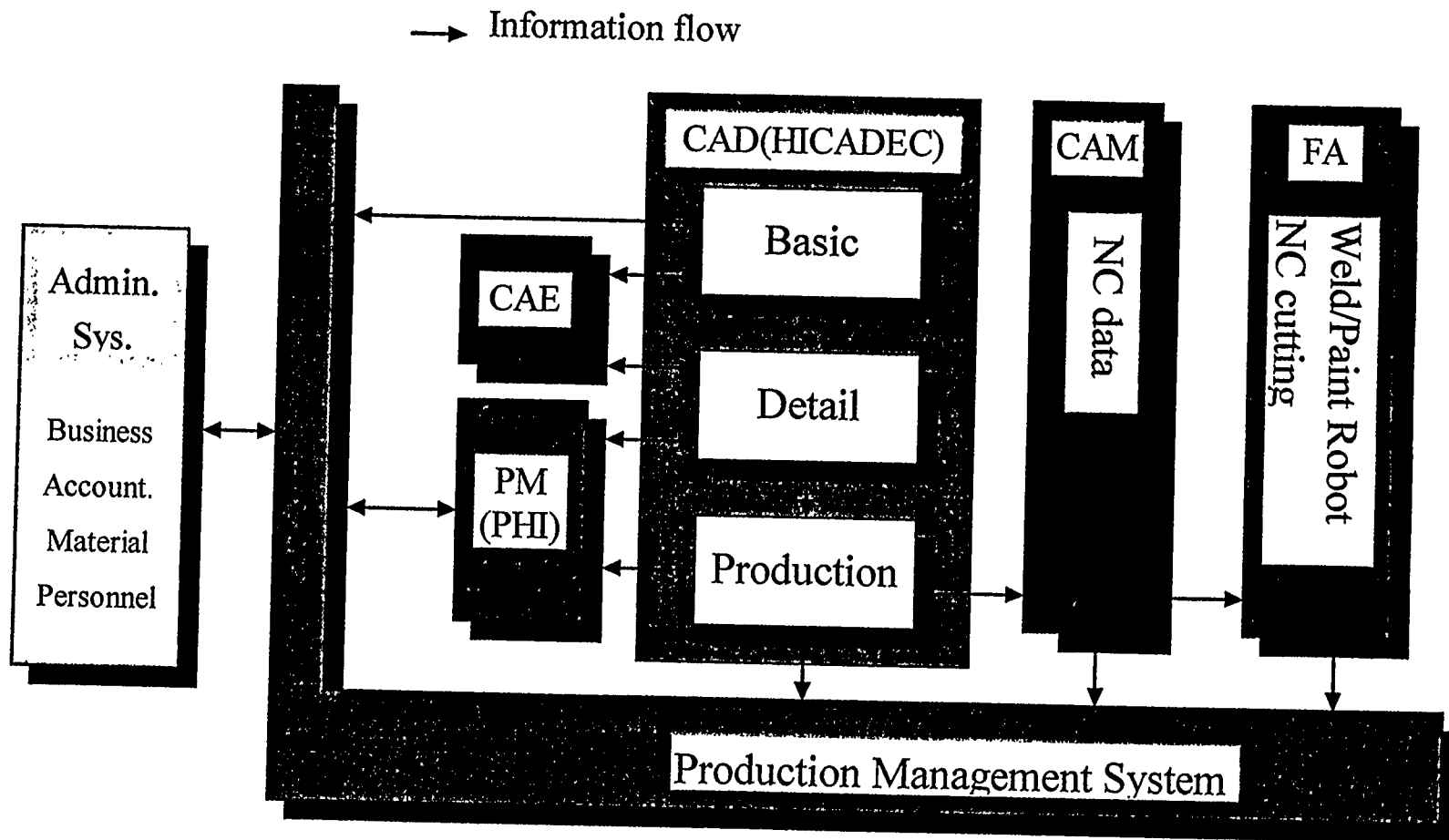


Figure 6.2

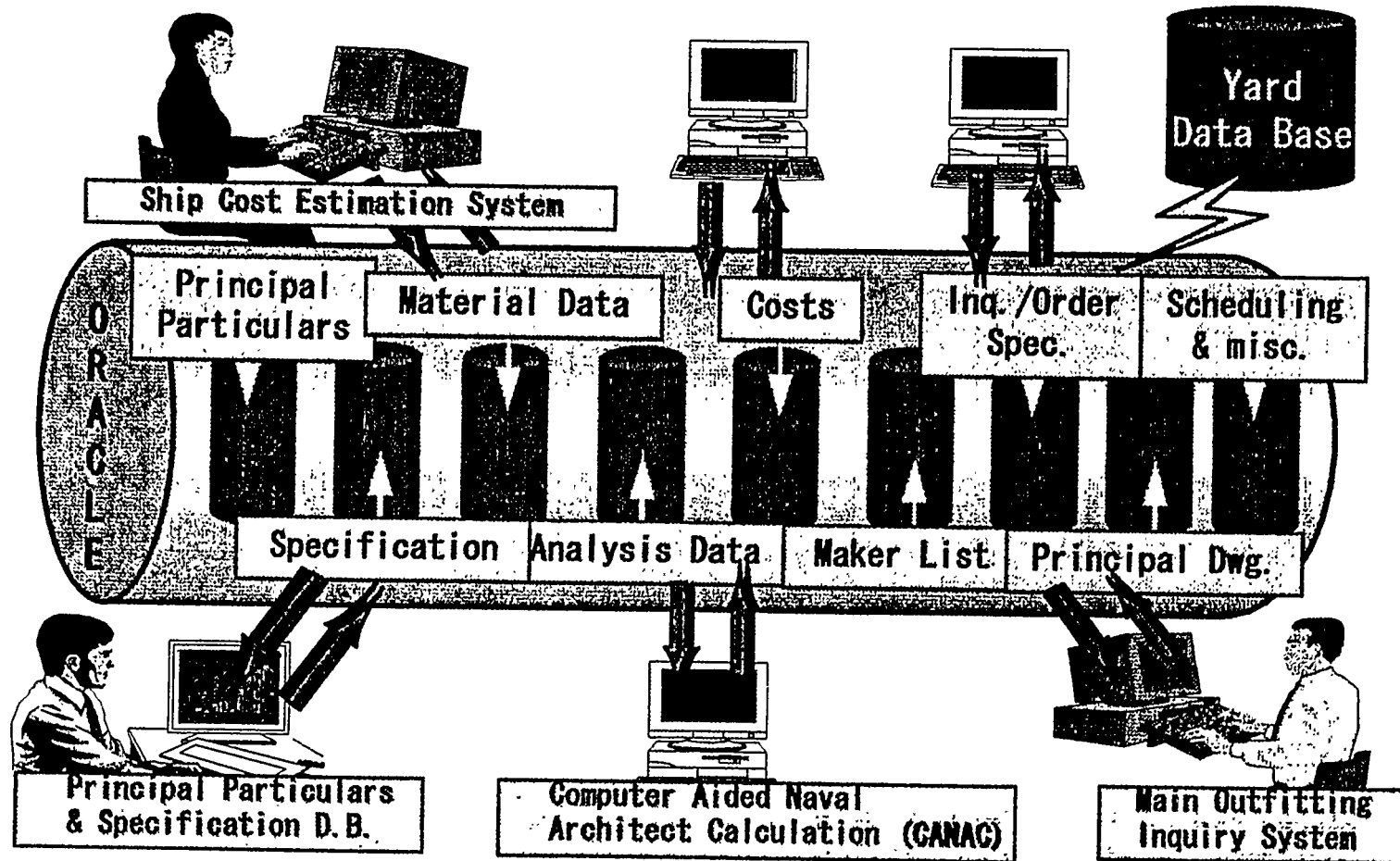
# CIM Concept of Hitachi Zosen



Hitachi Zosen

Figure 6.3

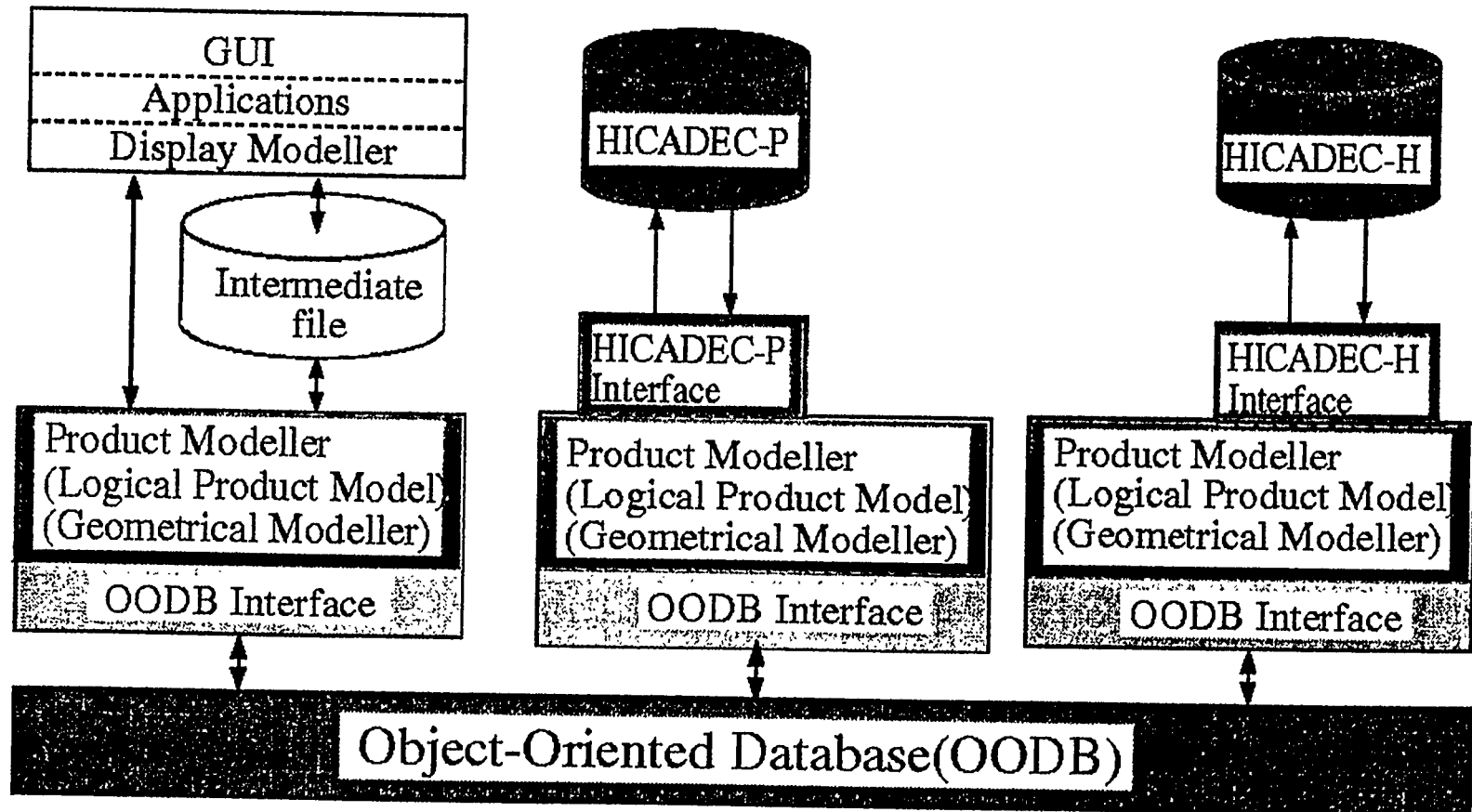
# Initial Design Integration Systems (IDIS)



Hitachi Zosen

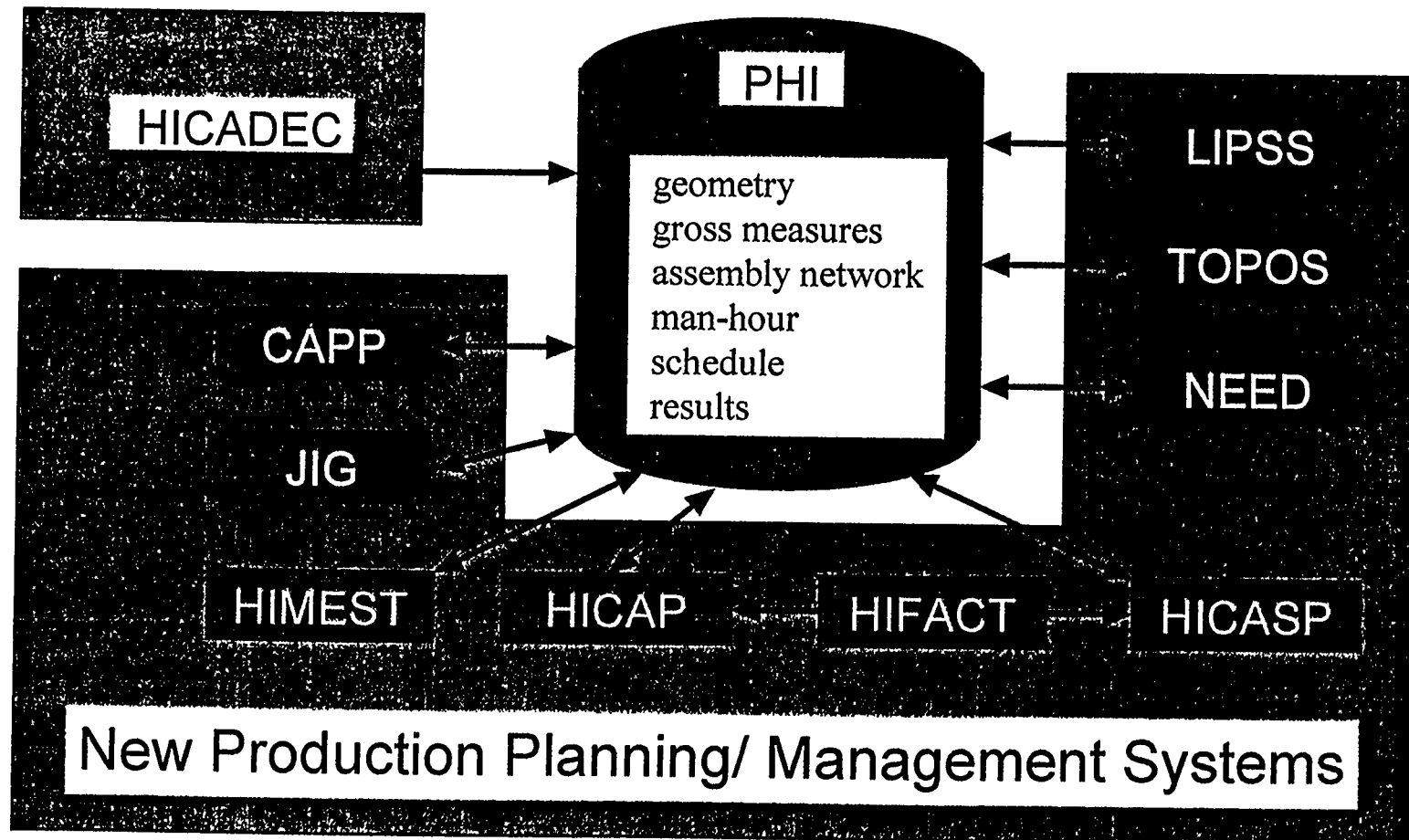
Figure 6.4

# System Architecture of PHI



Hitachi Zosen

# New Production Planning/ Management Systems



Hitachi Zosen

# Application Systems

---

- ◆ Man-hour Estimation System(HIMEST)
- ◆ Schedule Planning System by Shop Floor
- ◆ Schedule Planning System by Ship
- ◆ Process Planning System(CAPP & NEED)
- ◆ Lifting Planning System(LIPSS)
- ◆ Plan & Result Management System
- ◆ Paint Area Calculation System(TOPOS)
- ◆ Shadow Area Calculation System(LASC)

Hitachi Zosen

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- 5.4 Automation
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## **7.0 ISHIKAWAJIMA—HARIMA HEAVY INDUSTRIES CO., LTD.**

### **7.1 KURE SHIPYARD OVERVIEW**

IHI was founded in 1853 as Ishikawajima shipyard. Currently, IHI has sales of about \$ 10,800M (FY'94) and about 16,200 employees. Shipbuilding contributes about 19 percent (\$2,000M) of sales, second only to the energy and chemical plant segments (28 percent) of the business.

The Kure Shipyard was founded in 1946 when the Harima Dockyard Co. obtained a lease of the former Kure Naval Station. This Station, which commenced shipbuilding operations in 1889, built a number of famous warships, including the battleships “Yamato” and “Nagato.” A 1960 merger with Ishikawajima Heavy Industries produced IHI, which subsequently acquired Nagoya Shipbuilding, Shibaura United Engineering Co., and Kure Shipbuilding and Engineering.

The IHI Kure Works occupies about 371,000 m<sup>2</sup> (92 acres) and is situated between the harbor and surrounding hills. About 40 percent of this land area is occupied by buildings. Two building docks (510 meters and 295 meters) are served by 300 ton and 200 ton jib cranes, respectively. A large repair dock (320 meters) is also part of the shipyard facilities. The layout of the yard is shown in Figure 7.1.

Kure employs about 1200 workers; 900 of which are direct employees. This includes about 150 designers. The organization has five departments; Design, Construction, Repair, QC, and Production Control. Current production was suggested to be four to five vessels/year, primarily large Panamax bulk carriers and VLCCs. Construction time (from keel laying to launch) was said to be three to four months for these vessels.

The shipbuilding activities at IHI were characterized as not being profitable for the last seven to ten years. The reasons cited included very low pricing required to compete in a very competitive (overcapacity) market and the strength of the Japanese Yen. IHI is downsizing shipbuilding facilities by suspending shipbuilding at several works and converting these facilities to specialized manufacturing supporting shipbuilding and other parts of IHI businesses. The strategic plan calls for the Kure works to be the core shipbuilding facility and significant modernization efforts have been underway for the last year or two. These efforts include a modern new automated panel line and robotic welding stations for assemblies comprised of panel line products.

## **7.2 BUSINESS STRATEGY**

The Kure Shipyard builds and repairs a variety of primarily large-size merchant ships. VLCCS, large container ships and bulkers, and car ferries are primary products. The Kure Aero-Engine A Turbo Machinery Works adjacent to the Kure Shipyard also produces gas turbines for both land (electrical generation) and marine (warships) use.

## **7.3 COMPETITIVE STRATEGIES**

A great number of practical, low-cost production practices were evident during a brief yard tour. Gravity welding was used extensively, and an automated spray painting device was being used for final painting of the flat sides portion of the completed hull in the drydock. This was an “open air” painting device with no concern towards collecting or otherwise controlling fumes from the painting process.

As part of the IHI plan to regain competitiveness, the Kure Works shipyard will remain the principal assembly site for IHI shipbuilding. Other IHI Works, including Aichi Works, Yokohama Shipyard, Aioi, and neighboring Kure Shingu Works will build subassemblies as deemed appropriate for newbuilding projects. Aioi was mentioned as the site for accommodations and outfit packages work. Kure Shingu was mentioned for midsections work. The Tokyo Shipyard has been the site of Defense Force vessel projects and may continue to be devoted to this kind of work.

The Kure Shipyard is in the midst of a major modernization, emphasizing factory automation for steel production and upgraded CAD facilities in the design office. A major robotic welding facility was installed in the fall of 1994. A new panel line facility came on-line in August of 1995. Our visit to Kure was limited to one day because the facility was scheduled to begin a realignment to facilitate increased use of CAD in the design office. The principal CAD system used within IHI, the AJISAI system, is undergoing a major upgrade in a joint effort with Sumitomo.

## **7.4 FACTORY AUTOMATION**

Introduced this August, an automated panel line provides significant capacity in three primary functional areas; cutting, stiffener attachment to plates, and plate joining into panels. It was described as having sufficient accuracy to permit final cutting at the plate level through proper consideration of cutting tolerances and weld shrinkage. Finished product variations of +/- 3 mm in 16 meter widths and +/- 5 mm in lengths were described.

The panel line uses powered roller conveyors to move materials between work stations. The plate edges are NC cut (in air, plasma arc) and markings are applied for stiffener locations and/or bending locations. Preconstruction primer is removed at joint locations, and longitudinals are first fitted and tacked, then welded. Ten welding heads are available for two-sided fillet welding of up to five longitudinals at a time. Following welding, the heat affected zone (HAZ) is repainted by automated means and flattening rolls are used to remove weld distortion.

A large gantry welding robot facility was installed about one year ago for welding transverse frame assemblies to longitudinal stiffened hull panels. Only one weld head (out of four gantries with four heads each) was being used at the time of our tour. Judging by the sledge hammer and manual cutting fitup methods in use, and some sensitivity to observations regarding tolerances, it appears that limited accuracy maybe limiting the effectiveness of the robotic assembly facilities. The automated panel line brought on-line only two to three months prior to our visit may enable improved accuracy control once the processes are fully controlled.

## **7.5 MAJOR CAD/CAM/CIM SYSTEMS**

The current IHI approach to CAD/CAM/CIM seems to be a patchwork of stand-alone systems that are slowly being interfaced with each other. The AJISAI CAD system for hull structure (-H.) and outfitting (-F) form the heart of this system. R was described as being a solids model interactive system developed about three years ago. During the previous thirteen years, the FRESCA system was used. This was described as a wire-frame, command-operated system.

Preliminary design is accomplished primarily utilizing manual design and calculation methods. Reference 2-D drawings, typically of general arrangements and midship sections are prepared. A computer-aided preliminary design system is to be introduced next year. This system is expected to eliminate the need to develop 2-D drawings used to guide the 3-D CAD modeling in detailed design. Plans are also being developed to follow this automation of preliminary design with the development of an interface to classification society systems.

### **7.5.1 AJISAI CAD System**

AJISAI, the Japanese word for hydrangea, is a CAD/CAM system developed by IHI based on Computer Vision's CALMA DIMENSION-3 and AEC software. It was described as primarily a parts definition and display system. AJISAI consists of many independent programs grouped according to hull structure (-H) and outfitting (-F). The system is installed on an IBM-4381 host and utilizes via a variety of VAX, HP, and SUN

workstations (35) and PCs (70) all connected to a local area network (LAN). The main office in Tokyo and all manufacturing yard LANs are networked together.

The AJISAI system appeared to have minimal capabilities for topological modeling and connectivity between the structural (-H) and outfit (-F) data. A journal file system is used to repeat user commands used to generate one bulkhead in order to generate a similar bulkhead at another location. These journal files are also edited as necessary so they can be used to automatically regenerate designs based on revised dimensions. Interference checking between structure and outfitting can be accomplished only by visual inspection of graphic displays; collision detection algorithms are included in the current version of AJISAI.

A VAX Station demonstration of AJISAI utilized both a text terminal and graphics terminal without a tablet.

A recently announced joint effort with Sumitomo is expected to develop a significant upgrade to the AJISAI systems and better integration with preliminary design and production systems. This schedule for these developments was described as one year until introduction at IHI and Sumitomo. English language versions will be subsequently developed for world-wide sales.

### **7.5.2 CAM Software**

A variety of CAM applications software packages are used in conjunction with the AJISAI CAD system. These have been developed by IHI. Applications include nesting, NC cutting data generation, and welding robot NC motion data. A painting robot NC motion control data system is currently being developed in conjunction with a painting robot development project.

### **7.5.3 ASMIS System**

The Assistant System of Management Information for Shipbuilding (ASMIS) is a networked system for exchanging information between the IHI shipyards and the head office in Tokyo. Cost data during all shipbuilding construction are collected in the head office using this system.

### **7.5.4 KLEAN System**

The Kure LEAN system (KLEAN) is used for production planning, control, and progress monitoring. KLEAN is a stand-alone PC software product developed by IHI using Visual Basic. The system development is only partially complete and some of the planning is still accomplished by manual methods. Efforts are currently underway to interface the weld process information being developed in AJISAI and to extend the

system to automate some of the manual planning activities. These efforts are also expected to enable use of past sister ship data and enable timely LAN transfer of work schedule information from the Design Section to the production shops.

#### **7.5.5 SAINET System**

The Ship Building and Offshore Division Advanced Information Network System for Engineering and Technology (SAINET) provides LAN data exchange between the basic design and detail design departments. Data and messages are handled by this system. This system, and the ASMIS system described above, utilize wide area network (WAN) to exchange information with the head office in Tokyo.

### **7.6 PLANNING AND CONTROL**

Unlike the Mitsubishi and Hitachi yards, the IHI Kure Works has limited space for storage of interim products. Consequently, much of the production planning efforts focus on space allocation. The KLEAN system (see Section 7.5.4) is used on a stand-alone PC (i.e. no integration with AJISAI) to display block assembly status by process (loft, fab, assembly, store, etc.) and physical location within the yard.

Weld length, or number of weld portions for robotic welding, are primary parameters used for production planning and scheduling.

### **7.7 CAD/CAM/CIM INTEGRATION**

Little evidence of integration was observed. IHI participates with other shipyards in the Japanese Shipbuilders Association (JSA). Other JSA members (Kawasaki and Sumitomo) represent the JSA on ISO STEP standards. The integration efforts currently underway could be characterized as developing methods by which individual applications can be interfaced to exchange data.

Logimatic

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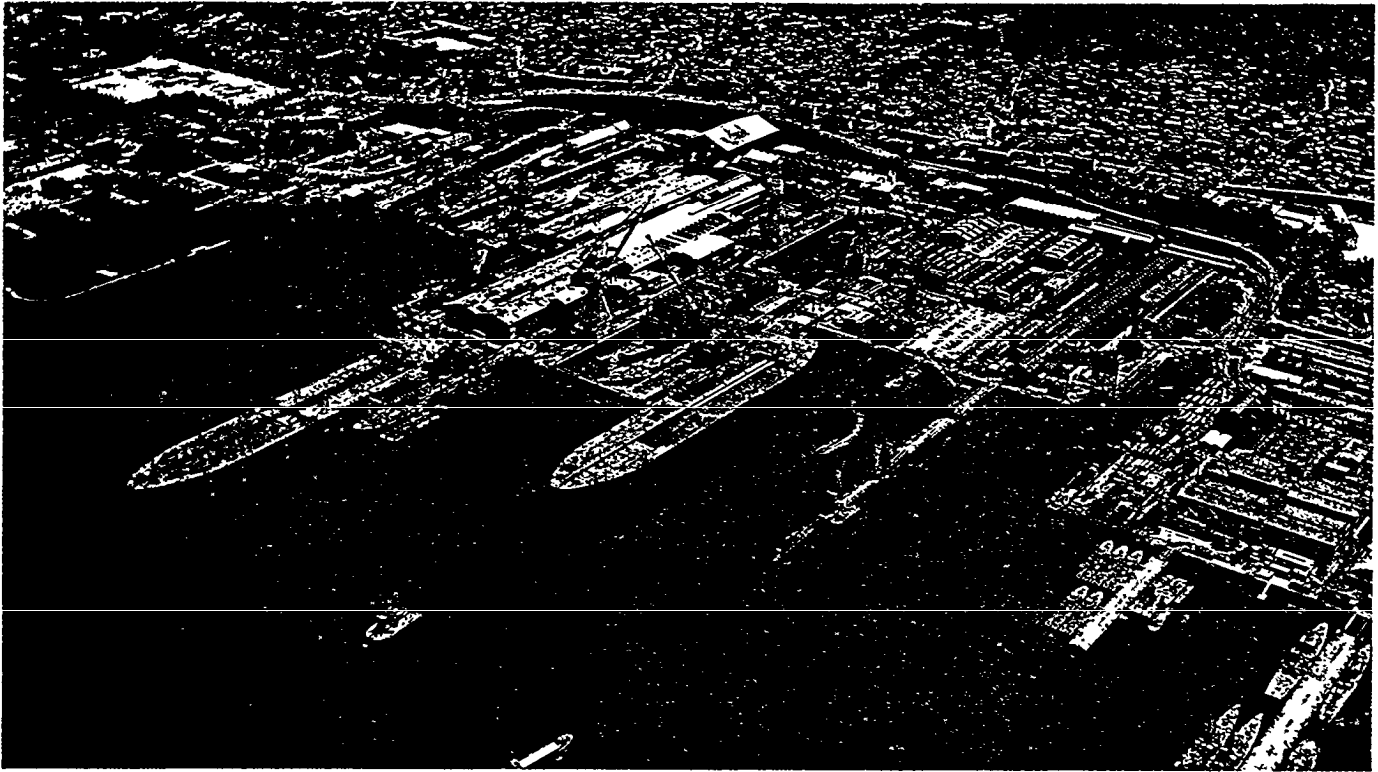
Sener Ingerieria Y Sistemas, S.A.

Fernando Alonso, Manager

Figure 7.1

# Equipped with Adequate Facilities for Construction of Merchant Ships of All Types and Sizes.

## KURE SHIPYARD

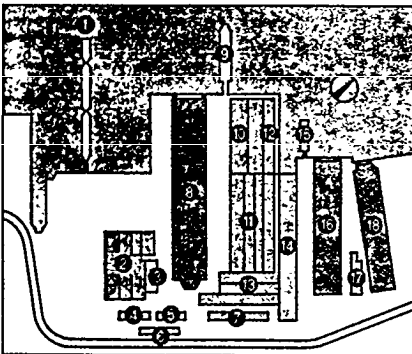


### Size of Works

Total land area: 270,745 m<sup>2</sup>

Total land area of the outdoor assembly yard:  
48,000 m<sup>2</sup> (Approx.)

Number of employees: 1,330 (Approx.)



- |                                  |                          |
|----------------------------------|--------------------------|
| 1. No.1 Pier                     | 10. Welding shop         |
| 2. Outfitting shop               | 11. Hull assembly shop   |
| 3. Coating shop                  | 12. Steel stockyard      |
| 4. Main warehouse                | 13. Welding shop         |
| 5. Annex office building         | 14. Steel plate workshop |
| 6. Main office building          | 15. No.3 Pier            |
| 7. General administration office | 16. No.2 building dock   |
| 8. No.3 building dock            | 17. Coating shop         |
| 9. No.2 Pier                     | 18. No.4 repair dock     |

### Features

Having a long history of building, Kure Shipyard has built all types and sizes of ships including 480,000 DWT class ULCCs, bulk carriers, container carriers, car ferries, pure car carriers, LPG/LNG tankers, large ocean-going tugboats and special-purpose vessels such as offshore rigs, derrick barges, as well as floating docks. Moreover, these products can be manufactured in quite a short time to delivery with high quality based on rational manufacturing process control and sure quality management. The 140,000 DWT-capacity repair dock is engaged in repairs and conversion of ships for Japanese Maritime Self Defense Forces as well as many other types of commercial vessels.

### Facilities

The facilities at the Kure Shipyard include

building docks equipped with cranes including the world's largest three 300 ton jib cranes and three 200 ton jib cranes.

The layout of the works has changed with the promotion of the installation of building blocks in 1993, while rationalization of manufacturing is being pursued at the same time with computer aided design and application of NC for in-house processes with the use of LAN between the works.

Blocks are painted in two specialized shops for coating and skin plates are painted by various kinds of painting robots in the dockyard.

Modularization and unitization of outfitting components are adopted widely in the outfitting shop to improve quality and working efficiency.

Dock No.	Length (m)	Width (m)	Depth (m)
No.2 Building Dock	295.00	50.00	11.15
No.3 Building Dock	510.00	80.00	13.50
No.4 Repair Dock	320.40	43.40	17.02

# **Evaluation of Shipbuilding CAD/CAM/CIM System Implementations**

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## **8.0 HOWALDTSWERKE-DEUTSCHE WERFT AG (HDW)**

The HDW Shipyard in Kiel, Germany and supporting organizations were visited on June 27-28. As part of engineering over the last several years, HDW has outsourced many of the support functions, such as electronic data processing (EDP), business systems (e.g. payroll, etc.), and CAD systems integration, with factory automation. Two of the support organizations, Norddeutsche Informations-Systeme GmbH (NM) and SMK Ingenieurburo GmbH were visited in addition to the shipyard to better understand how the HDW network of small companies worked together. HDW and NIS are both members of the Preussag Group, with NIS aligned as a subsidiary part of HDW.

### **8.1 HDW SHIPYARD OVERVIEW**

Originally founded in 1838, the present HDW company was organized in 1968 as the consolidation of three shipyards in Kiel and Hamburg. Shipbuilding is now mostly concentrated in the most modern of these yards, the Kiel yard. In addition to the Kiel yard, HDW is the parent company for the HDW-Nobiskrug shipyard, the Ingenieurkontor Lubeck submarine design office, the MARLOG naval logistics firm, NIS, and a few other subsidiaries.

### **8.2 BUSINESS STRATEGY**

HDW touts high-tech ships incorporating some of the latest innovations in ship configurations and systems. Container ships without hatch covers, fast cargo catamarans, and environmentally acceptable tankers are offered along with LNG tankers, multi-purpose freighters, ore/oil freighters, cruise liners, passenger and car ferries, and hydrogen transporters. The order book over the last 25 years includes over 200 ships of widely varying types and designs. Microprocessor-based ship operation and management systems have been introduced into merchant shipping. Fuel cell systems, originally developed for submarine use, are also being developed for commercial surface ship applications.

### **8.3 COMPETITIVE STRATEGIES**

With the extreme price pressures accompanying world-wide shipbuilding overcapacity during the last decades, HDW has struggled for profitability in commercial shipbuilding. Ongoing Navy submarine work and some contracts for frigates and corvettes for the German Navy and on export sales, has helped. CAD/CAM technology was introduced in 1985 with the objective of developing more information in the design

office and significantly reducing the production costs and schedule. Upon introduction, the costs (man-hours/block) in the design office immediately doubled. After three ship contracts, these design costs have returned to pre-1985 levels and much of the intended production cost savings have been achieved. The transition time was suggested to be about NO years - longer than anticipated. Similarly, welding robotics, which were anticipated to have a two-month transition time, actually took six months to implement.

A key principle guiding the HDW efforts to enhance profitability was to re-engineer business processes first, before attempting to automate these processes. The 80/20 rule of going for 80 percent implementation with 20 percent of the cost was adhered to in developing process improvement plans. These plans and their underlying concepts were evaluated annually and adjusted by experience to-date. Hardware (NC and robotics) vendors and software vendors were involved in the planning.

An aggressive accuracy control program appears to have been recently initiated at HDW. Key features include a plate (and profile) marking methodology, an AICON camera system for monitoring dimensions in the panel line, and multiple passes of materials through a single-head plasma cutting station. This approach to cutting clearly sacrifices the production time advantage of multiple-head cutting for what was described as very important dimensional control (i.e. minimal variability). Profiles are milled to -0/+2 mm height tolerances with the attachment edge also squared to remove the “bulge” inherent with rolled stock.

Following an analysis of three to four years of production cutting and weld shrinkage data, a university professor has devised the measurement strategy and implementation methodology for monitoring and controlling dimensional variability. A key feature of this strategy is the marking (i.e. torch scoring) of measurement control points on plates and profiles in the cutting workcells. For decks, bulkheads, and hull plating “blankets” the measurement markings are added after the blankets are fabricated (joined) from individual plate pieces.

## **8.4 AUTOMATION**

HDW is currently introducing factory automation in NC cutting (plasma and gas), profile cutting, and robotic welding. At the current level of implementation, not all productivity targets have been achieved. A key problem area was described to be the interface between the CAD system and the robotic off-line programming (OLP) system. This problem is being addressed through efforts by HDWS automation company (NM) and COTS software vendors. Further implementations are also being planned to extend robotic welding to additional applications.

## **8.5 MAJOR CAD/CAM SYSTEMS**

Most of the HDW CAD/CAM/CIM systems descriptions were provided by SMK and NIS. The TRIBON system is the primary hull structure system for both submarine and merchant ships. TRIBON is used for merchant ship outfitting, but the Applicon BIL4V0 system continues to be used for submarine applications. The NAPA suite of naval architecture programs is used for hull form definition and hydrostatics calculations.

The SHIPPS development project was briefly described as a joint effort by HDW, KCS, NIS, NAPA, and possibly Germanischer Lloyds to develop more effective preliminary design tools. The current system is comprised of traditional NAPA programs supplemented with what appears to be word processing and spreadsheet applications. NAPA programs are used to define hull forms, layouts, initial steel structure, and routes for distributed systems. These programs also calculate weights and quantities used to estimate material and production costs. The current system of separate programs was described as requiring too much time to complete preliminary designs and tender offer estimates. Advanced macros in some of the NAPA programs are apparently key features to this development effort.

## **8.6 NORDDEUTSCHE INFORMATIONEN-SYSTEME GMBH (NIS)**

Founded in 1985, NIS has grown into a rather large computer software and consulting firm. Revenues were 16M DM in 1995 with employment of 90 people. The business systems portion of the firm (another 60 people) was recently setup as an independent company, leaving NIS to focus on the technical issues. Their primary contributions to HDW are in the areas of integration between HDWS TRIBON, BRAVO, and MEDUSA CAD/CAM systems and their business process and factory automation systems - primarily production planning and control, and robotic cutting and welding.

NIS is free to market software and services to companies and shipyards other than HDW. They are being encouraged to market their products and services to others in order to provide the financial leverage to reduce their costs to HDW. Currently, most of the NIS work is for HDW and six other smaller German shipyards. Their first real contact with U.S. shipbuilders is with Ingalls, with whom they indicate that they are spending considerable time.

### **8.6.1. Production Planning System (PPS)**

Originally developed on an IBM mainframe computer, the PPS system is currently being converted to a UNIX clientserver environment.

### **8.6.2.RoboPlan**

RoboPlan is an off-line programming software package that is interfaced with several CAD/CAM packages. Initial development programs were sponsored by the German government and shipyard industry in the 1987-1992 time frame. Two universities (Berlin and Aachen) assisted with some of the initial development. NIS continued the development after 1992 and introduced RoboPlan into production at the HDW shipyard in 1994. A key interface between the structural CAD system, TRIBON, and RoboPlan was described as not 100 percent complete. Informal discussion suggests that KCS was to complete the CAD side of the interface by June of 1995, but has not yet been able to deliver/demonstrate this interface. Compatibility with the ACM kernel based graphics developed by NIS for RoboPlan appears to be part of the interface problem. Principal competitors to the NIS RoboPlan system were suggested to be ROBIN (Odense Steel Shipyard) and TTS Norway.

The emphasis in RoboPlan development seemed to be on error-free programming speed, and utilizing product model data downloaded from the CAD systems. Commercial software (e.g. ROBCAD and IGRIP) was evaluated for use in RoboPlan, but was not used due to the emphasis on graphical simulation rather than fast programming. Some of the significant features of RoboPlan include;

- Off-line programming using planning fictions (macros) and CAD-based geometry and seam descriptions without need for on-line or off-line teach-in.
- Utilizes “neutral file” interfaces to diverse CAD and robotic systems. This appears to be the result of a collaboration between KCS, HDW, NIS, and several Japanese shipyards also utilizing the KCS TRIBON CAD/CAM system.
- Automatic programming of similar constructions and movements between welding seams (i.e. transfers). Currently, this appears to require user intervention for determination of similar constructions. Automation of this determination is under development.
- Integrated welding database and expert system for weld procedure selection and programming of suitable torch head positions, orientations, and associated welding parameters (e.g. welding speed, current voltage, gas shielding, sensor paths for tolerance compensation, etc.). The welding database contents are controlled by a welding engineer.
- Suitable for overhead and vertical welding as well as down-hand welding.
- Collision detection is done by simulation either in foreground (interactively) using coarse time steps, or in background (batch mode) using fine time steps. Typically, robot program code generation is automated, complete with batch mode verification (collision detection) of both welding and transfer paths. Only faults (i.e. collisions, axis limits, etc.) are reported, which are then resolved by the

interactive replanning capability that can be used to override the automatically generated code.

- . User-definable movement patterns based on self-adapting macros and user defined search length.
- **Integrated with production planning and control systems via completion signals** for daily accumulation of construction progress information.

### **8.6.3. DiNCos**

The DNC operating system (DiNCos) provides centralized DNC administration for merging NC data with work order instructions, and tracking production status, workload, and machine state information. It is based on a SYBASE relational database and operates in a client/server UNIX environment. NC data produced by the RoboPkm system are stored in DiNCos and merged with production instructions received directly from the production planning system (PPS). Complete work order instructions are generated from the merged NC data and production instructions. In the event of a process failure (e.g. an unsuccessful robotic weld) the system incorporates recovery procedures that prevent inappropriate attempts to repeat process steps until manual intervention resolves a suitable solution.

The software was described as modular, thus enabling expanded connectivity with additional and/or new DNC machines. As with most of the NIS software, the DiNCos system is commercially available without restriction by HDW.

### **8.6.4 Lead Control**

Lead Control is a shop floor system for controlling production equipment such as robots, transportation systems, and NC machines. It utilizes graphical displays of the workpiece part or subassembly superimposed on the workcell base. The base is equipped with a grid of locating holes used to orient a workpiece properly for the required process and to allow automated control of the complete process. The system integrates administration of the data to various devices or cells in the work center and allows control between the devices as well as feedback concerning progress of the workpiece.

### **8.6.5. CIPS 2000**

CIPS 2000 is the rule-based CAM system for manufacturing of piping systems. It is specifically designed for efficient generation of production data and NC programs supporting both shipbuilding and plant design applications. Production process rules and equipment capabilities are defined in the system, which then uses this information to generate simulations and automated creation of production data required to manufacture

the piping component. Functionality includes process administration steps for feedback and material control.

## **8.7 SMK INGENIEURBURO**

SMK Ingenieurburo is a small engineering consulting company engaged in shipbuilding computer applications development implementation, and long term support. The firm was founded by three former HDW employees. One principal owner has significant experience in use, sales, and support of KCS TRIBON used at HDW and many other German shipyards. This knowledge, combined with practical knowledge of shipbuilding processes, combines to make SMK an effective consultant to German shipyards. This consulting role is consistent with German shipyard's need to downsize all aspects of their organization in order to remain cost competitive.

SMK competes for HDW subcontracts in detail design and production engineering. Since HDW will farm out a large part of the work, SMK is one of a number of subcontractors using TRIBON to deliver design and production documents to HDW. SMK is currently responsible for nesting.

SMK maintains similar relationships with other shipbuilders in northern Germany and the surrounding Baltic countries. Through these relationships the Team was introduced to Logimatic and Caretronic as two additional small engineering consulting companies engaged in support of shipbuilders.

## **8.8 LOGIMATIC AND CARETRONIC**

Logimatic and Caretronic both have their roots in major shipbuilding companies. Logimatic is an applications developer for material ordering and control systems starting with a core of personnel in electrical design from the current Danyards. Caretronic specializes in piping assemblies and fit-up pieces supporting both the shipbuilding industry and fabrication for process plants. Caretronic's founder was the architect for the HDW piping design system implemented in Applicon's Bravo.

Logimatic provides a suite of applications for material identification and management. Its applications have been integrated into the TRIBON system by KCS and are separately available from Logimatic for direct integration into other CAD/CAM systems.

Caretronic provides both applications and consulting services to its clients. The applications are available for workstations and support both piping design and production engineering products. Output is available for automated pipe fabrication. A

unique application is an automated and patented mock-up fixture which allows on-site detailing of field fit make-up pipe spools. The device is completely field portable and consists of a number of interlocking precision components that model straight pipes, pipe flanges, pipe bends, elbows, etc. The components are fitted between existing or fixed points of a piping systems. A PC is connected to the data port of the mock-up fixture and all information to detail the spool is downloaded and processed in the PC. Output is then available to fabricate and check the make-up spool.

Both Logimatic and Caretronic are interested in marketing expanded services to other shipbuilders internationally. They represent a type of service available to European shipbuilders based on a geographically tight collection of large and small shipyards and heavy industry that have downsized and need professional support of process innovation.

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A list of participants on the shipbuilding CAD/CAM/CIM evaluation project team is included in Appendix H. Likewise, the participants from the above organizations are also listed. The preparation and open discussion by these participants were instrumental to these evaluations.

## **9.0 VEROLME**

### **9.1 VEROLME SHIPYARD OVERVIEW**

The Verolme Shipyard Heusden (VSH) was founded in 1909 by de Ham & Oerelemans to build inland vessels. In 1953, the yard was taken over by Mr. Verohne and switched over to building seagoing vessels. In the seventies and eighties, the Verolme Shipyard was a member of the Rijn Schelde Verohne Group until a management buy-out in the late 1980s. In 1992, Verolme became a member of the Wilton Feyenoord holding conglomerate.

Verolme is located at the outer walls of the renovated town of Heusden on the Maas river in southern Netherlands. Vessels produced at Verolme must pass under two fixed bridges on their way (100 km distance) to the North Sea for delivery. These bridges limit the height of constructions that can be completed at the shipyard to 17 meters from the keel to the top. Final assembly, usually installation of the superstructures, masts, cranes, etc. is done by Verolme people at a Rotterdam location. The superstructures built at Verolme are transported by barge. Other yards maybe employed for deckhouse constructions as appropriate to support the work schedule at Verolme.

The permanent facilities include a 40-ton crane, which determines the maximum block size for most shipbuilding. Mobile cranes are periodically employed for 50-80 ton lifts required for some blocks constructed of thick (40 mm) plate. Except for the recent cutting facilities, very little automation was evident in the workshops. The design office, containing about 40 workstations in clusters of four, looked uncluttered, professional, and included ample workspace around the workstation facilities. The design office layout was open (no partitions) and located all on one floor.

Employment at Verohne is about 400 people, organized in the following departments;

Project Department	11
Design/Engineering	40
Planning	4
Block Section Assembly	150
Erection on Slipway	136
Pipe Workshop	10
Machinery Workshop	20
Carpenter Workshop	10
Warehouse	4
Office	15

The Design/Engineering Department is organized by the following disciplines:

Hull Modeling	12
Hull Work Preparation (nesting)	5
Accommodations	3
Pipe Modeling (outfitting)	8
Work Preparation outfitting	2
Others	10

Atypical shipbuilding contract schedule was described as about one year in duration as follows:

<b>Week</b>	<b><u>Description</u></b>
0	Contract signing, begin design (lines fairing, midship scantlings)
4	Start hull modeling, initial steel plate order placed (eight week delivery)
12	Start of production in workshops and slipway (28 week duration)
41	Launch, begin final outfitting and trials (twelve week duration)
53	Delivery and sea trials

## **9.2 BUSINESS STRATEGY**

VSH'S business is somewhat diverse, building small to moderate size (1 100 TEU) container vessels, hopperdredgers, passenger and car ferries, heavy lift vessels, chemical carriers, research vessels, tugs, and reefer vessels. The maximum ship size is 200 meters in length and 32.5 meters in breadth. They provide full service, from product design to detailed engineering, production planning, construction, and outfitting.

## **9.3 COMPETITIVE STRATEGIES**

In most areas, VSH shares engineering and production work with other yards in order to "load-level" work in the design office and workshops. A three-person design office is also employed periodically. Outside services are used for many overhead activities. For example, EDS provides payroll and related services to Verolme through a primary contract with another Wilton Feyenoord Group shipyard.

## **9.4 AUTOMATION**

NC plasma/gas cutting facilities were installed in 1995. This represents the only current factory automation as most of the shops remain low overhead facilities, relying on

a very skilled labor force rather than on capital investment in facilities. Plate forming was done by roll and press forming, no line heating methods are used.

Future development needs were described as welding robots for block assembly (5-year horizon) and automation in the pipe fabrication shops, including pipe nesting. Weld shrinkage and bend/stretch dimensional prediction and control were identified as significant issues relative to these automation efforts.

## **9.5 MAJOR CAD/CAM SYSTEMS**

The STEERBEAR steel structure CAD system, running on a Digital VAX VMS system was introduced at Verohne in the 1990-91 timeframe. Following a three month evaluation trial based on a past ship design, the Kockums Computer System's TRIBON system was introduced in 1995. This system is running under open VMS on an Alpha 1000 server and accessed by 22 Alpha workstations and 20 X-terminals. Digital Equipment provides service on the hardware under a maintenance contract.

Software is essentially all COTS. A Dutch software company provides the Naval Architecture programs used for hydrostatics, calculations, etc. Kockums TRIBON provides the CAD software used primarily for hull structure and piping design. It is also used for block weight and CG calculations. A U.S. software company provides the nesting software. Verohne is in the process of acquiring and implementing a production control software package from a Finnish company.

Data exchange between the design office and the production workshops is done by floppy PC disk or tape transfers. There are no electronic data networks connecting the design office with the workshops in the shipyard itself.

## **10.0 KOCKUMS COMPUTER SYSTEM**

Kockums AB is a subsidiary of the Celsius Industries Corp., located in Gothenburg, Sweden. Celsius is an industrial group concentrating on defense industry markets. This group also includes Bofors (weapon systems), Celsius Tech (electronics systems), Telub (information technology), and others. In addition to marine technology and engineering services, the Kockums group produces submarines, Navy and Coastguard surface vessels, and shipbuilding design and information systems software. The software products are developed, maintained, and supported by Kockurns Computer Systems AB (KCS).

In the late 1960s, Kockurns developed the STEERBEAR system to facilitate the large amount of materials flow and design work needed to support a large number of orders placed with the Kockums Shipyard. In 1977, the KCS company was founded in response to interest by a number of European shipyards in this design and information system. In 1988, KCS acquired the rights to the Norwegian AUTOKON system and, in 1992, KCS acquired the rights to the German SCHIFFKO system. In 1993, KCS introduced the TRIBON system, combining the best features from these earlier systems.

During the NSRP evaluation team's visit, KCS described efforts to redeploy support resources by closing their Norway office, downsizing their German office and opening offices in Korea and the USA. Most of the \$8.5M R&D spending in 1994 (up from \$4.0M in 1993) is focused on TRIBON development. About half of this expanded R&D is customer funded for specific developments.

To provide better technical support world-wide, KCS is developing means to utilize Internet and electronic database transfers to augment telephone support from local offices and Mahno. KCS also utilizes user meetings, workshops, and reference groups to exchange information and needs with its customer base. Recently, they have instituted a top management advisory group to facilitate customer-driven development programs.

### **10.1 TRIBON OVERVIEW**

A variety of hardware platforms and operating systems are supported by TRIBON. These include UNIX in client/server configurations, and selected applications operate on PCs using DOS, MS-Windows, or Windows NT.

#### **10.1.1 Database**

Much of the effort to include an SQL-compliant database (using Oracle software) has been completed and is being used to integrate both TRIBON and third party

applications. The original proprietary KCS geometric modeler “engine” is being replaced with the ACES modeler utilized in many commercial CAD applications. Windows NT and Windows 95 are considered the future operating systems of choice.

### **10.1.2 General/Conceptual Design**

The TRIBON family of shipbuilding applications is a suite of ship design programs including; hull form geometry, hydrostatics, stability, longitudinal strength, and speed/power. KCS has acquired BMT and has integrated its (NURBS-based) hull form modeling. Interfaces to NAPA-Oy software exist. The University of Hamburg has developed an interface to its own FEA software from Stearbear (which may not be compatible with TRIBON) but no commercial FEA packages have been or are being interfaced. The initial design capabilities include a tendering application for assembling cost estimates.

In a joint project with Det Norske Veritas (DNV), KCS is developing rule checking and analysis programs for direct calculations of design performance. These tools are also expected to address the exchange of data between shipyards and DNV for classification society approval.

### **10.1.3 Structural Design**

The TRIBON Hull module was demonstrated for adding transverse bulkhead plates to an existing product model. This latter demonstration highlighted some of the strengths and weaknesses of the system. Most noticeable was the lack of graphical user interface capabilities to make simple changes (e.g. plate thicknesses). Cryptic command lines in a text file had to be edited and the bulkhead regenerated based on the edited command lines to accomplish these rather simple kinds of changes. The text file editing appears to require significant understanding of UNIX script command lines used to store the product model data.

Simple, empirical-based weld shrinkage tables can be input and used to adjust part sizes and stiffener spacings to allow for weld shrinkage in assemblies. In cooperation with the Japanese, KCS is further developing weld shrinkage prediction methods for more complicated assemblies involving constituent parts having different stillnesses and other shrinkage-affecting characteristics.

The structural package has no associativity with the hull, piping, and electrical aspects of the product model database. It is considerably more advanced in user friendliness, permitting changes to be made using interactive graphics modeling methods without having to use text file editing.

#### **10.1.4 Outfitting Design**

Piping Module, Part Definitions, and Nesting were demonstrated followed by brief demonstrations of the Electrical and Structural (foundations) modules. The piping and electrical modules appear to be quite similar to each other with functionality essentially the same as in most CAD packages

#### **10.1.5 Associativity and Interference Checking**

Associativity (topology) between hull, outfitting, and electrical disciplines can be utilized in the modeling. Electrical is fully associative with equipment. Piping can be partially associative with hull structure (e.g. penetration locations but not sizes). Once piping has been connected to equipment the equipment cannot be moved without first disconnecting the piping. After the equipment has been moved, the piping must rerouted to the new flange location and foundations must be adjusted. Electrical cabling to equipment connections are updated automatically if defined in associative fashion.

Interference checking is done in batch mode only. No geometry is stored in the object-oriented database product model. Consequently, each interference check is done by mathematical analysis. The user can reduce the scope of these calculations by selecting (point and click) only two or three objects to check for interferences.

#### **10.1.6 Configuration Management**

Commercial shipbuilders have not historically required Configuration Management (CM) capabilities, which are commonplace for Navy work. KCS anticipates that somewhat different (than Navy) needs will soon be identified by commercial shipbuilders.

### **10.2 IMPLEMENTATION APPROACHES**

The Japanese implementation process was described. This is typically a three-year process. A one-year evaluation and benchmarking period is followed by a one-year pilot project. At the end of the pilot project a very specific and detailed implementation plan is formulated, which includes KCS product enhancements and organization changes needed in the shipyard to maximize benefits. Once implemented in a Japanese shipyard, several subcontractors are developed to assist the shipyard. These subcontractors are required to output design and production products in exactly the same form as the shipyard. They are given customization software developed by the shipyard to facilitate duplication of capabilities and are required to establish electronic data exchange of TRIBON product models. The Finland shipyards are less insistent on standardization, and subcontractors compete primarily on the basis of price.

### **10.3 PRODUCT MODELING TECHNOLOGY**

RIBON incorporates successful product modeling approaches from its legacy systems. These include STEERBEAR AUTOKON, and SCHIFFKO. The majority of the product modeling representation available in TRIBON appears to come directly from STEERBEAR. Additional capability is being added to account for the differences between new and existing customers needs. Customers are directly involved with various national efforts to standardize shipbuilding and ship design product model descriptions. KCS is working directly in these efforts and is supporting selected industry partners in test and evaluation efforts.

### **10.4 INTEGRATION**

#### **10.4.1 Factory Automation**

Considerable attention is being paid to welding issues. A neutral file format standard is used to output welding information to a robotics program interface database, which is used by simulation software and welding robotics manufacturers.

#### **10.4.2 Production Planning and Scheduling**

An assembly tree approach is used to define relationships between parts. This feature provides functionality to organize the product model data according to discrete assemblies. Each part in the product model can be associated with an assembly. Assemblies can be composed entirely of parts or combinations of subassemblies with or without additional parts. The usefulness of this feature is in the ability to generate graphics (e.g. drawings) and/or parts lists of specific subassemblies. If so implemented in a shipyard (e.g. by a numbering scheme), the product build strategy and work breakdown structures can be developed in advance of actual product design.

Hierarchal trees showing the constitutive assemblies and loose parts for each sub-assembly can be described. These are displayed in tree diagrams showing all parent-child relationships. A specific assembly or group of assemblies can be “click and dragged” to a window, which then displays the characteristics (including part numbers) for the assemblies. Assembly graphics can also be created (but not displayed) in this module. Graphics thus created can be displayed in one (or more?) of the graphics modules.

### **10.5 TRIBON FUTURES**

The strategic plan for the TRIBON product seems to be moving towards increased use of third party products utilizing industry standards to facilitate integration

with other functional software. For example, KCS is in the process of developing a relational database that will work in conjunction with the existing proprietary object-oriented database. This strategy permits shipyards to utilize their preferred scheduling, software, etc.

Some of KCS product development plans for TRIBON were discussed. The relational portion of the database currently under development will have an SQL interface. Work has been initiated to implement ACIS as the geometry modeler, and TRIBON plans to implement Open GL for graphics. Similarly, plans are being formulated to implement a Windows NT version.

KCS is looking at knowledge-based systems in the areas of optimizing assembly sequencing and weld sequencing to maximize efficiencies for assemblies (e.g. minimize welding time). This capability is being developed based on Japanese requirements. KCS is giving some thought to knowledge-based systems for planning but doesn't seem to believe there is short-term potential in this area.

Based on KCS'S involvement in STEP, a configuration management capability need has been identified. A design has not yet been developed. KCS is looking for a TRIBON customer to help in the design.

Another area they have given some thought to is interfacing or integrating with computational fluid dynamics (CFD) analysis tools.

## **1.0 EXECUTIVE SUMMARY**

Commercial shipbuilding orders have been increasing world-wide and, for certain product segments, are expected to experience continued strength, possibly for several decades. This follows a 10+ year period during which weak demand could not sustain the available capacity resulting in subsidized prices, voluntary production limits, and numerous shipyard consolidations and closings. With an eye to the more recent market expansion, new capacity is now being added, most notably in regions previously not participating in any significant shipbuilding. These regions tend to enjoy labor cost, currency exchange rate, and modern facility advantages over the world's traditional shipbuilders in Europe and Japan.

The world's traditional leading commercial shipbuilders have not been idle. In efforts to profitably compete in today's shipbuilding markets characterized by over capacity and extreme price pressures, these yards have developed various strategies to significantly reduce shipbuilding costs and schedules. The strategies include aggressive business practices, new or significantly enhanced computer technologies, factory automation, capital investments, and an unfaltering attention to process discipline and continuous process improvement. Computer-Aided Design (CAD) technology has been evolving in these shipyards since the 1970s. In the late 1980s and early 1990s this technology has been significantly enhanced through the addition of Computer-Aided Manufacturing (CAM) and factory automation, especially in cutting and welding. The 1990s is seeing the integration of these engineering and production technologies with planning and business systems. Truly Computer-Integrated Manufacturing (CIM) is emerging as one of the technologies of the 1990s by which world-class commercial shipbuilders plan to maintain or return to profitable competition in world markets.

This project's Phase 1 Assessments of shipyards and software developers provides both overview and depth into "world class" commercial shipbuilding operations. Shipyards in both Europe and Japan were initially studied which combined profitable operation and extensive use of computer technology in their operations. Later, specific assessments were conducted regarding use of commercially available CAIYCAM shipbuilding software in smaller or "2nd tier" shipyards.

As seen in Figure 1.1, all shipyards studied have some of the highest average labor rates and the lowest labor content per CGT (compensated gross ton). These yards were selected in order to provide the best information concerning possible direction for U.S. shipbuilders approach to new CAD/CAM/CIM systems to achieve even better results than those studied. Our assessments indicate that this performance is a result of aggressive business practices which:

- . provide on-going market share and business backlog
- . continue profitable operation in spite of relentless price and schedule competition

## **11.0 SENERMAR**

Sener Ingenieria y Sistemas, S.A. was established in Bilbao, Spain some 35 years ago. Today the company is split between locations at Tres Cantos in Madrid and Las Arenas in Biscay (near Bilbao). Sener's roots are in the shipbuilding industry. The company was founded by naval architects and these founders are still in place today. The Managing Director of the company is a naval architect. When the company was started in the 1960s it was as a marine company exclusively. The diversification into other industries began in the 1970s.

Currently, Sener is a broad scope engineering company, including nuclear power and process plant design, highways, aerospace, and marine. Sener offers a full range of professional services including feasibility studies, basic engineering, detailed engineering, project management, purchasing, construction management start-up assistance, and system integration. The company has a variety of quality standards necessary for work in the space, nuclear, and aeronautics industries. Sener has ISO 9001 certification and utilizes quality standards appropriate to specific projects, including 10CFR50 and ANSI/ASME NQA1 for nuclear power work. Current staff numbers 817, of which over 60 percent are consultants and engineers. The company has participating relationships with the following engineering companies: Gestec SA, Ensitrans, Mets% and J.B.-Sener. It has participating relationships with the following industries: ITP S.A., Zabdgarbi, Sergarbi, and Arianespace.

Senermar is the Marine Division of Sener. This division supports two business activities - computer systems and ship engineering services. The computer systems activity centers around the development, maintenance, and marketing of the FORAN Shipbuilding CAD/CAM System. They currently have 110 installations in 20 countries.

Ship engineering services cover a full range of ship design services, technical studies, and technical assistance. Services include contract design (lines, midship, naval architecture), basic or class design (technical documentation required for classification approval), and detailed design (including shop information). Recent contracts include; factory freezer trawler, aircraft carrier, logistics support ship, product tanker, and floating production storage offshore. Three projects were underway at the time of the NSRP project team visit; a reefer ship basic design, barge carrier conversion to a 250 meter long FPSO, and a basic and detailed design of a new 215-meter long FPSO for Texaco. Senermar utilizes its FORAN shipbuilding software to provide design and manufacturing information to shipyard clients.

## **11.1 FORAN OVERVIEW**

FORAN is a shipbuilding-oriented CAD/CAD/CAM system. Work on the initial system started in 1965. The system was marketed in 1969. The system is made up of tools for general design, followed by hull structure, drafting, conceptual design, and outfitting. Senermar is currently finishing a new state-of-the-art electrical design system.

The FORAN shipbuilding CAD/CAM system operates on Hewlett-Packard (HP) UNIX workstations using NFS networking for client-server capabilities. Software modules have been written in C and FORTRAN.

The FORAN system is organized into subsystems, or modules, which are designed to be modular, flexible, follow a straightforward development line, and cover scope from concept through production. The modules are listed as follows:

- . General Design
- . Conceptual Design
- . Hull Structure
- . Drafting
- outfitting
- Electrical Design (currently in final development)

The current product represents a highly integrated CAD system utilizing a central product model database and supported by well-developed drawing production capabilities. Figure 11.1 provides an overview of the geometry, structure, and outfitting product modeling capabilities of FORAN. These CAD product models are fully integrated and can be interfaced to other functional systems in a shipyard as listed in Figure 11.2. Data lists and files can be extracted from the CAD database through use of a report generation language.

The FORAN outfitting system has been used by Sener on the European Community (EC) advanced fighter aircraft engine project and occasionally for chemical process plant piping design.

### **11.1.1 Database**

The FORAN database is proprietary. Indications are that it is a network, transaction-oriented system. The system apparently provides for automatic recovery of transactions to the last stable place. A single database is used for both structure and outfitting. This database can contain one or multiple hulls. Senermar claims that their proprietary database requires rather modest file sizes (one quarter

space requirements) compared with other systems. 200 MBytes is common for an entire product model, with 300 MBytes about the largest in Senermar experience. The database management system stores only structural topology and equipment parameters. The database accommodates multiple, concurrent users.

Projects are currently underway to link to the INJFORMIX database for material system with a shipyard in Spain. Another project is underway to put all (nongeometry) attribute data in an Oracle database. Translators are said to have been developed (by Senermar) for the CALMA and INTERGRAPH systems. An interface exists for the CAESAR application to support pipe stress analysis. Development of an interface with MAESTRO to support Finite Element Analysis (FEA) is being discussed. Senermar is also discussing with Lloyd's the possibility of integration with their FEA software.

3-D .DXF files can be input directly into FORAN, as well as 2-D .DXF files. Luis Garcia (Senermar Marketing Manager) did not believe that AutoCAD 2-D .DXF files can be input into the 3-D model without considerable modeling effort. Similarly, 2-D AutoCAD design/drafting standards are not readily converted into FORAN 3-D parametric definition standards.

### **11.1.2 General/Conceptual Design**

The General Design Module covers seakeeping, hydrodynamics, hydrostatics, hull geometry, and other naval architectural analyses. Hull geometry is comprised of hull form definition including hull form generation, fitting, and faking, definition of decks and bulkheads (through parametric surface definition), and the generation of lines, body plan, and general arrangements drawings. A new hull form capability using NURBS (Non Uniform Rational B-Spline) was said to be ready shortly.

A P&I Diagram (PID) module is included. The objective of this module is to enable the design office to develop sufficient information early in the design process to generate a Bill of Material (BOM). This module incorporates equipment and piping. Attributes for each equipment item, including a P&I symbol, are maintained in databases of standard components and unique items. A one-directional associativity between the PIDs and the 3-D product model also provides a tool for subsequent development of the 3-D product model.

Luis Garcia (Senermar Marketing Manager) strongly suggested that general arrangements can be easily done in 3-D using FORAN in the preliminary and contract design phases. This facilitates the subsequent development of the 3-D product model compared to other systems that utilize 2-D arrangement drawings that must be converted to 3-D models in the detailed design phase.

### **11.1.3 Structural Design**

The hull structure design packages were demonstrated in detail. The model used in the demo was a 300,000 DWT E3 (Economic Ecological European) tanker. The first ship of this contract was to be delivered in September 1995. The ship was built in the Puerto Real yard of Astilleros Espanoles. The demonstration was conducted alternatively on Data General and Hewlett-Packard UNIX workstations and X-Terminals to show the systems flexibility and the commonality of the user interface. It was repeatedly emphasized that FORAN does not require high-end, high-performance UNIX workstations to be an effective tool.

The demonstration began with hull form definition. The system apparently uses its original 1960s code to perform this function, although the user interface has been updated. An updated version using NURBS is under development and is planned to be ready in 6-9 months. Structural parts are defined in terms of surface intersections. Should either surface be later modified, the part definitions are automatically updated based on their associative definition. Blocks of hull structure can be established by geometric boundaries in order to associate default attributes to parts defined within the block. A significant use of parametric standards was evident for penetrations and other recurring features. Large panels are defined by outer contours such as seam and butts. The panels are broken down into plates by selecting "limit" seams. It is basically a lofting system working with molded lines.

The use of grid lines and super profiles in hull structure modeling was demonstrated and the use of grid lines for topological modeling was described. Associativity between member end-cuts and the profile (or other structure) configuration to which the member is attached was demonstrated. This consisted of transverse frame intersection with a cambered main deck. The stiffener to stiffener intersections and parametric endcuts (parallel to intersected deck) were successfully obtained. Bevel definitions on profiles are limited to those profiles which are perpendicular to the plating to which the profile is attached. The generation and use of template, heating lines, and pin jig data was also described.

The structure design system was very impressive as a functional and detailed design tool. One interesting feature was the "superprofile." Superprofiles are an option to define longitudinal (typically) in, say, functional design. The superprofile is later broken down to individual stiffeners based on block, etc. The attributes of the superprofiles including endcuts are passed down to these individual stiffeners (i.e. children of the parent superprofile)..

#### **11.1.4 Outfitting Design**

The outfitting module was described as having associativity between pipes and fittings. Use of the one-directional associativity between the Process and Instrument Diagrams (PIDs) and the 3-D product model was described. Components or equipment included in the fictional diagrams, but not positioned in the model, are detected by the system. Build strategy zones are not defined at the PID level but rather at the 3-D modeling stage.

The equipment library module used to develop the PIDs is also used for 3-D outfit design. This library includes true 3-D solid representations of equipment. It appears that CSG (Constructive Solid Geometry) constructs using parametric primitives (i.e. cones, cylinders, prisms) are used for these 3-D representations. Equipment can be positioned to any structural reference. It should be noted that the relationship between structure and equipment is currently for positioning only. Topological functionality is being developed for an upcoming version. With this capability, if a deck moves, a pump attached to it will move also.

A general outfitting structure module is used to model miscellaneous hull outfitting items such as foundations and hangers. The user selects standard foundation parts from a library. The foundation parts are linked to points in structural model. The foundation parts are parametrically defined, that is, automatically sized from the foundation to the backup structure. A pipe module is used to define pipe runs between equipment items. Designers can select between bent pipes or commercial elbows as well as other attributes for material and fabrication process selections. Shipyard specific files for describing spring back, radial growth, and clamping distance requirements.

An electrical design application is currently under development. The team was given a presentation of the part of the system that has been completed. The new system focuses on three areas:

- Power and Lighting
- . Control and Instrumentation
- . Routing of Wires

### **11.1.5 Associatively and Interference Detection**

FORAN was described as having a powerful interference checking mechanism functioning throughout the product model, that is, between structure and outfit. Interference detection can be done automatically during the insertion or modification of an item in the CAD system or upon user request in a batch mode. Soft interferences (operating space requirements) as well as hard interferences can be detected by the on-line or batch collision detection capabilities.

### **11.1.6 Work Preparation**

Several modules are included in the FORAN system for generating workshop information assembly sketches, profile sketches, jig pin height data, bending templates, line heating lines, and profile shape sketches with bending information. One module generates piping isometric spool diagrams complete with bending information. Spool parts are user selected and the ID numbering can be automatic or manual. The next version of this module is expected to include pipe hanger information. A significant level of drawing automation was observed, including the work preparation modules. The electrical design package currently in final development will provide a connection sheet as output for the electrical installer.

A nest module is included for the nesting of structural plate parts. The system provides a menu (similar to the Autokon AUTONEST program) of all parts with the correct quality and thickness. The system is semiautomatic and checks to make sure that the parts have not been previously nested. Nesting and cut sequencing is independent of cutting machine but topologically related to 3-D product model part definitions. Cutting machine controller(s) information is postprocessed from the FORAN database, utilizing customized software developed by Senermar as part of the implementation. To date, no FORAN customers utilize robotic welding so the interfaces to robotic controllers or off-line programming (OLP) systems have not been developed.

## **11.2 IMPLEMENTATION APPROACHES**

Based on Senermar's considerable experience with shipyard implementations of CAD/CAM systems, they described the responsibilities believed necessary for a successful implementation. These include management involvement at all levels as outlined in Figure 11.3. Similarly, the training process was described as outlined in Figure 11.4. It was highly recommended that first line management also be trained to ensure proper motivation of the design staff to utilize appropriate approaches and modeling methods. Topological (associative)

modeling approaches require some foresight regarding spatial relationship such that topology can be used effectively in making design revisions.

### **11.3 PRODUCT MODELING TECHNOLOGY**

FORAN is comprised of product models for geometry (hull, decks, bulkheads, compartments), structure (primary and detailed), and outfitting (piping, hvac, and cabling). Each is reported to be fully integrated. The product model descriptions can include attribute information related to planning/scheduling, purchasing/procurement, and quality control. Information can be extracted from the FORAN database and passed to other applications. The discussion did not include specifics on how this is done or whether information could be passed into FORAN from other applications.

The BUILDS module, which provides for defining the assembly sequence in terms of tree structures, supplements the traditional CAD part descriptions. This capability was described as having an unlimited number of assembly levels. Individual parts can be assigned to their locations in the build strategy tree structure by graphical (point and click) methods. Both hull structure and outfitting trees are supported. The hierarchy structure is as follows:

Supertree  
    ship  
        User-defined interim products (many)  
            Block  
                Normal tree  
                    Individual parts

The user defines a supertree level (e.g. ring for submarine), defines the next level (e.g. subring), then assembly, then interim levels such as subblock, panel, sub-panel. Once these levels are defined, parts can be selected graphically and assigned to appropriate element in tree structure. A graphical representation shows the parts in the tree. Parts can be picked by either FORAN identification or user-defined name. Outfitting is done the same way. Senermar is currently working on a way to integrate the two. A sample report of the hierarchy was shown indicating whether parts were designed, purchased, fabricated, and mounted/installed for each item.

## **11.4 INTEGRATION**

The emphasis appears to be in product model integration rather than system integration with specific third-party vendor's software. Interfaces to a shipyard's specific NC equipment are developed by Senermar as part of the implementation. To date, no FORAN customers utilize robotic welding so robotic interfaces have not been addressed. The focused CAD development approach provides flexibility for shipyards to use their preferred systems for production planning, material control, and purchasing.

## **11.5 FORAN FUTURES**

Most of the current FORAN development effort is focused on CAD tools such as enhanced visualization tools and an electrical design package. Work has been initiated on the visualization capability with a third-party vendor, DIVISION. Enhancements to hull form surface definitions (NURBS based) are underway to more effectively interface with third party products addressing hull form definition. Graphical user interface improvements are also being undertaken to implement icons and tool bar concepts, as well as to provide some standardization of window layouts. Some effort is contemplated in production planning systems for those shipyards who yet do not have such systems.

The strategic plan for the FORAN product seems to be focused on development of superior CAD tools that can be integrated with CAM and CIM tools provided by others. UNIX platform independent software seems to be a guiding principle with software code written in generic C and FORTRAN languages. Figure 11.5 outlines the future product development plans for FORAN. Senermar is also working with Det Norske Veritas (DNV) on CAE methods to facilitate classification design and approval process. Improved tools for preliminary and contract design appears to be a focus for future developments.

The following list of future enhancements and development initiatives was presented. Details on priority or release sequence and schedule were not shown.

1. Product Model Walkthrough Capability
2. Materials Management
3. Accommodation Design
4. Integrated Logistic Support (ILS)
5. Configuration Control
6. Management of Design Modifications
7. Alternative Definition of Surfaces
8. Reengineered User Interface

Figure 11.1

## PRODUCT MODEL DESCRIPTION

- **FORAN product model includes three categories of information:**
  - topological relationships
  - technological properties and other attributes
  - 3D geometry
- **FORAN data base:**
  - application oriented (proprietary)
  - single
  - multiaccess
  - security and integrity of the information
- **FORAN has a powerful interference checking mechanism**
  - automatic (active during the design process)
  - upon user request
- **Product model walk-through capability is coming.**

Figure 11.2

## **CAD/CAM SYSTEM INTEGRATION**

### ■ **FORAN product models:**

- geometry (hull, decks, bulkheads, compartments)
- structure (primary, detailed)
- outfitting (piping, cabling, ducting)

**fully integrated!**

- **FORAN product models include data related to Planning/Scheduling, Purchasing/Procurement and Quality Control.**
- **The information is extracted from FORAN data base and passed to specific applications.**
- **New integrated models and planned for development.**

Figure 11.3

# MANAGEMENT INVOLVEMENT IN CAD/CAM/CIM STRATEGY

## ■ CAD/CAM TECHNOLOGY HAS STRONG IMPLICATIONS IN THE SHIPYARD

### ■ EXECUTIVE MANAGEMENT SHOULD:

- Decide the Implementation strategy
- Take active part in the decision process

### ■ FUNCTIONAL AREA MANAGEMENT SHOULD:

- Analyze in-house CAD/CAM/CIM performance
- Periodical survey of the CAD/CAM market
- Suggest executive management installation improvements

### ■ FIRST LINE MANAGEMENT

- Key level in the CAD/CAM success
- Know in detail the CAD/CAM system capabilities
- Organize and control the end-users work
- Product model quality control
- Suggest improvements to software vendors

Figure 11.4

# TRAINING PROCESS

### ■ PERSONNEL SELECTION

- SKILLFUL DESIGNERS
- COMPUTER KNOWLEDGE

### ■ USERS MOTIVATION BY FIRST-LINE MANAGEMENT

### ■ TYPICAL SEED-GROUP TRAINING SCHEDULE

	1	2	3	4	5	WEEKS
GENERAL DESIGN	1	2	3			
HULL STRUCTURE		1	2	3		
OUTFITTING		1	2	3	4	
ELECTRICAL DESIGN				1	2	

### ■ INTERNAL TRAINING CONDUCTED BY THE SEED-GROUP

### ■ START-UP TECHNICAL ASSISTANCE

### ■ CONVENIENCE OF A CRASH-TRAINING FOR FIRST-LINE MANAGERS

Figure 11.5

## **FORAN MAIN FUTURE DEVELOPMENTS**

- **PRODUCT MODEL WALK-THROUGH CAPABILITY**
- **MATERIALS MANAGEMENT**
- **ACCOMODATION DESIGN.**
- **INTEGRATED LOGISTIC SUPPORT (ILS)**
- **CONFIGURATION CONTROL.**
- **MANAGEMENT OF DESIGN MODIFICATIONS.**
- **ALTERNATIVE DEFINITION OF SURFACES.**
- **NEW USER INTERFACE.**

# APPENDICES

	Design			Production					Operations Management				
	Conceptual/Preliminary	Functional	Detailed	Fabrication Processes	Joining and Assembly Processes	Surface Treatment & Coating	Material Control	Testing/Inspection	High-Level Resource Planning and Scheduling	Production Engineering	Purchasing/Procurement	Shop Floor Resource Planning and Scheduling	Quality Control & Assurance, SQC
Structure													
Outfitting													
Interim Products													

Appendix B

**Odense Lindø**

**THE PLANNING SYSTEM**

**AT**

**ODENSE STEEL SHIPYARD LTD.**

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**INTRODUCTION TO A-B-C PHILOSOPHY**

**IN**

**PLANNING**

## PLANNING AF ODENSE STEEL SHIPYARD

The Yard divides planning into several levels ensuring both coordination and activity flow within each area. Therefore our newbuildings are delivered on time and available resources are efficiently utilized.

Planning is performed on 3 levels - each considering the following purposes (Encl. I):

A-PLANNING is the superior level for planning and control across all functions at the Yard. A-planning covers the complete order stock.

B-PLANNING is dedicated planning and control of production flow of each product. Furthermore B-planning forms the basis for detailed planning in each production department and the drawing/material scheduling.

C-PLANNING is the detailed tool for planning and control of all activities within respective production areas or departments.

The planning system is fully computerized and forms the central operating tool. It is directly connected to the Yard's other systems, e.g

CAD Systems

Bill of Material Systems

Material system

Wage system

## A-PLANNING

A-PLANNING is the superior tool for management planning and control (Encl. 2).

A-PLANNING covers both the complete order stock and inquiries; time horizon is 2-4 years.

# Odense Lindø

The purpose of A-PLANNING is

to specify dates for all main functions on the first newbuilding in a series right from contract signing to delivery (A-Coordination plan).

to specify the key dates for each newbuilding (ship):

Production start

Keellaying

Launching

Departure

Delivery

The result of this process is the “Construction Schedule”. The “Construction Schedule” is authorized by the managing director.

to analyse workload based on contractual hours and consecutive hours. The analyses support - on both the short and the long view - the management decisions concerning

Employment

Dismissals

Changes in skills

Education

Allocation of contracts (sub-contractors)

Optimizing of “Construction Schedule”

to follow up on consumption of manhours in each planning area -in cooperation with the production management - enabling revision of manhour estimates each month.

to form the basis for physical follow up of selected milestones covering a large number of the Yard's main activities.

A-PLANNING is carried out by Department for A-Planning. This department is also responsible for the total Planning System and related computer HW/SW as well as the administration of databases and reporting.

# Odense Lindø

## B-PLANNING - PRODUCTION

B-PLANNING - PRODUCTION is the Yard's superior production management system and basis for the detailed planning in all other departments such as design, production engineering, purchasing etc. (Encl. 3).

In order to secure validation of A-planning, B-planning already starts during contract negotiations and it continues after placing of order (Phase 1) so that the first edition forms the basis for generating drawing- and material programmed.

The B-plan always reflects the main events in the "Construction Schedule" provided by A-planning.

The purpose of B-PLANNING FOR PRODUCTION is

- to determine the blocks and areas (zones) forming the basis for construction of the newbuilding.

- to schedule the activity flow of respective blocks, areas and outfitting installations (based on production methods) which then forms the basis for determination of drawing- and material terms.

- to indicate - in correspondence with the plans - the superior product division (description of the work content of each activity) as a basis for work load analyses.

- to form the basis for planning at C-level.

- to form the basis for follow up on actual construction status.

- to analyse and conclude workload consequences of plans specifying the need of resources for respective activities. The objective is the shortest possible construction period within acceptable workloads.

B-plans for production is prepared by the Production Engineering Department. The plans are to be approved by the production management within respective areas.

The B-plans are constantly improved reflecting the generation of more and more detailed design, improvements in processes, plant, equipment etc. Follow up allows a very precise evaluation of status.

# Odense Lindø

## C-PLANNING, PRODUCTION

The purpose of C-PLANNING is to form a coordinated basis for the production management, department by department. C-planning covers all activities in each area within a 12 weeks horizon (Encl. 4).

The Managing Director, Production approves the results of the 12 weeks planning and use them as basis for his superior work load dispositions.

The production manager uses the first four weeks as basis for his internal dispositions. They are updated every two weeks.

Within a two weeks horizon the detailed order plan is described and respective area managers have to approve it. The plan is updated every week.

The purpose of C-PLANNING FOR PRODUCTION is

- to break down B-plan activities (if necessary) in order to achieve an activity structure corresponding to actual and individual need of a job.

- to specify dates for all activities in an area.

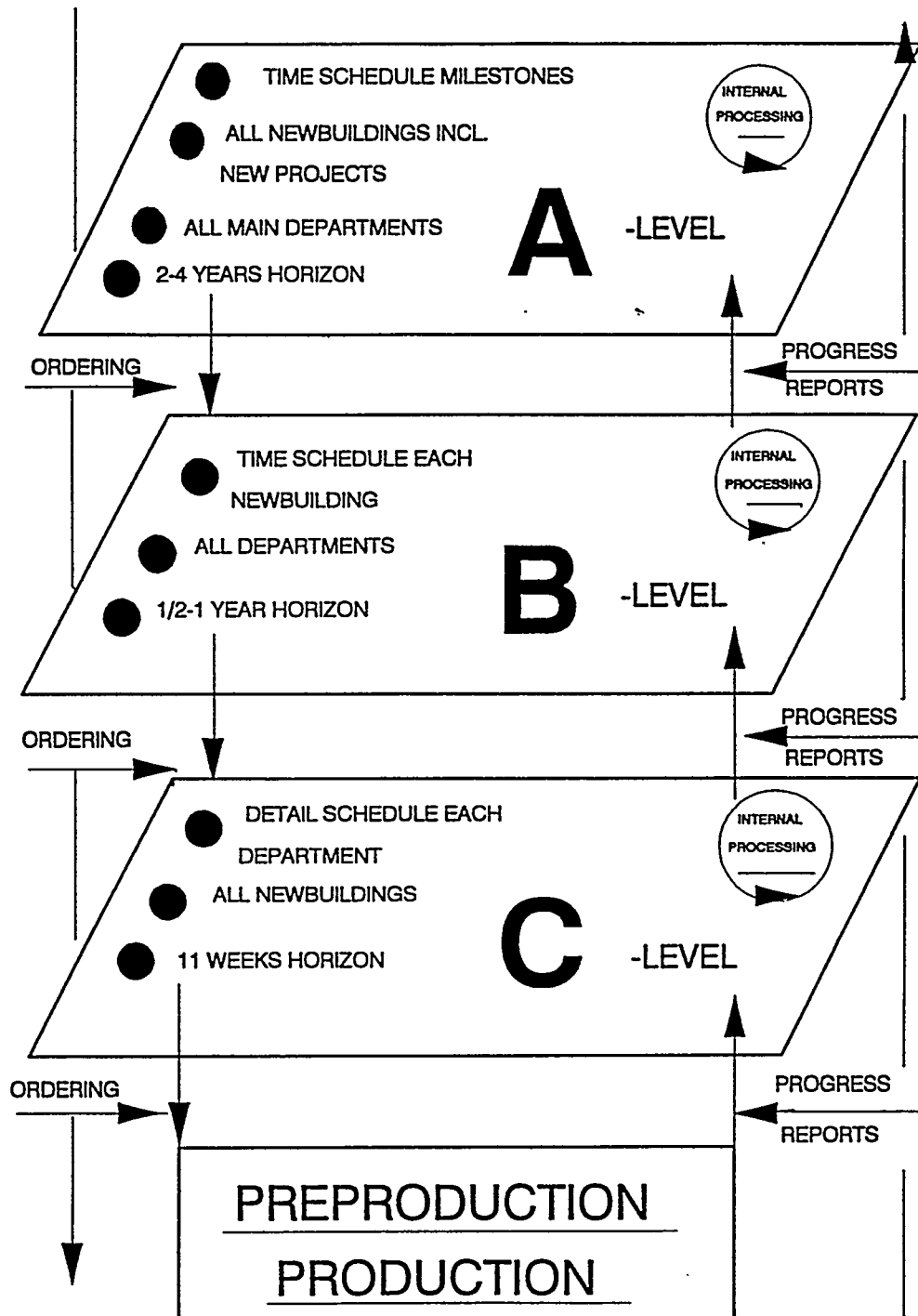
- to calculate the workload consequences of plans and to adjust the plans in order to reach an acceptable workload within the frames set by the B-plans and with the best possible use of plant and machinery.

- to form the basis for daily follow up and determination of corrections necessary to keep the agreed production milestones.

Preparation of C-plans for production is carried out by each production department.

Area workload analyses are carried out as further documentation of C-plans and these analyses show how area has to be used day by day.

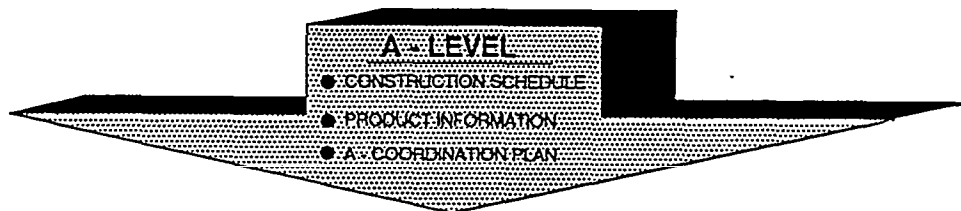
## PLANNING SYSTEM



# **A - PLANNING TASKS**

- . ENQUIRY RESPONSE**
- . A - COORDINATION PLANS**
- . MASTER SCHEDULE (KEY DATES)**
- . WORKLOAD**
- . FOLLOW UP - MANHOURS**
- . FOLLOW UP - MILESTONES**
- . CORPORATE INFO ROOM**
- . SYSTEM ADMINISTRATION**

## B - PLANNING TASKS



- B-LEVEL**
- PREPARE DIVISION IN BLOCKS AND AREAS
  - DETERMINE BUILDING METHOD/ACTIVITY FLOW
  - CALCULATE AREA REQUIREMENT FOR EACH ACTIVITY
  - CALCULATE PRODUCTION HOURS FOR EACH ACTIVITY BY TRADE
  - PREPARE B-PLANS
  - WORKLOAD CALCULATIONS
  - PLAN OPTIMIZING
  - DESCRIBE PREREQUISITES AND WORKLOAD
  - COMPLETE INFORMATION AND APPROVAL PROCEDURES





• **GENERATE DATA**

- TRANSFER FROM B- TO C-LEVEL
- BREAKDOWN
- SUPPLEMENT/UPDATING

- ESTABLISH C- PLANS
- ANALYSE WORKLOAD
- ANALYSE AREA
- OPTIMIZE PLAN
- PRODUCE PLANS AND WORKLOAD  
TO PRODUCTION MANAGEMENT

FINAL BASIS FOR PLAN



FEEDBACK

**FOLLOW-UP DURING PRODUCTION**

FEEDBACK



## **Appendix C**

### **STEEL PRODUCTION AND OUTFITTING AT ODENSE**

#### **C.1 STEEL PRODUCTION**

The Odense steel processing facility features three mainlines; main plating, miscellaneous small parts, and profiles. The nesting for main steel is driven by production schedule, small parts for brackets, collars, etc. are not generally included. Surplus plate after cutting is measured and added to a database of smaller stock plates to be used for brackets and other smaller parts. It was explained that Japanese steels are preferred because of their low carbon content, better tolerances, and cleanliness. Danish and other European steel mills are used since feedback from Odense has prompted them to tighten tolerances and cleanliness standards. For a typical large newbuilding (e.g. the 293,000 DWT VLCCS), Odense uses seven suppliers to provide the required 7,400 plates and 13,300 profiles.

##### **C.1.1 Plate Cutting and Marking**

An order is placed with the supply mill for approximate quantities at a fixed cost to be delivered over the duration of the series construction contract. “Standard” plate sizes are not utilized. Exact plate material size requirements are communicated to the supply mill with 10-12 week lead time prior to delivery. Widths and minimum lengths are purchased. Each plate of incoming material is numbered and stored outdoors in pairs of stacks by block. As a specific plate is needed to support upcoming production of a block, the plates are shuffled to uncover the appropriate plate which then enters the steel fabrication facility.

Incoming steel is roll-flattened, blasted, cleaned, and primed upon receipt in the steel production facilities. Steel abrasive powder is used and not recycled. The primer was described as 11 microns of inorganic zinc (Hempel 2S 1572 zinc silicate). Weld through the primer was observed in panel and plate assemblies utilizing one-sided welding. Some concern about problems with weld quality (porosity) were mentioned in association with welding through the primer.

Plate materials are cleaned and primed but not brushed in the future joint areas. These plates are next cut to shape and cutouts are made on submerged mc cutting tables. The steel fabrication facility has five (5) plasma and four (4) flame cutting machines for cutting steel plate parts. One of the plasma machines had its marking system recently replaced with an inkjet marking system. They are very happy with the results; the ink actually penetrates into the primer and stays far more visible than zinc oxide even after abrasion. The plates are marked before they are cut. Pforile trace curves, layout lines are marked as well as textural information such as part ID, hull number, nest ID, etc. Frame

numbers are offset from the molded trace curves such that the numbers are visible after welding of members to the plate.

Nesting is currently done using the HICADEC-H software. A new nesting program capable of nesting 700 parts in 1.5 hours is being acquired and will be introduced shortly. Surplus plate from the main plate cutting is inventoried and sent to a bracket/collar/small part NC cutting area. The PMS system (see Section 4.6.1) is used to track surplus plate inventories to be used in the bracket/collar/small part cutting area.

### **C. 1.2 Profile Manufacture**

The design preference at Odense is to use built-up sections in lieu of rolled shapes. Higher costs (15%), less stringent dimensional tolerances, and limited production schedules (3-4 times per year) are inconsistent with the Odense low cost, stringent dimensional control, and just-in-time production methods. The practice employed for the 4800 TEU container vessel seems to include both built-up sections and rolled bulb flats. Much of the dimensional tolerance requirements stem from Odense's practice of "threading" profiles through cutouts in frames after the frames are fitted to panel sections. **These cutouts are cut to  $\pm 1$  mm tolerances to facilitate final welding of the frames and profiles.** Two separate profile fabrication lines in the steel shops provide for rolled shape cutting and built-up profile fabrication.

The production line for producing built-up T-bars is automated and efficient. The capacity was stated to be 25,000 T-sections/year. Webs are cut slightly oversize from plate stock by a Messer Griesheim OMNIMAT plasma arc cutting machine with eight (8) Hypertherm heads cutting at speeds of 2500 mm/min. A machine with a mechanical milling device grinds the edges of the flange bars for final tolerance dimension. The same machine also mills weld bevels and/or 45-degree bevels for better paint adhesion. This process is followed by a mechanical device that removes paint from the center of the flange using a sandpaper wheel. Another Messer Griesheim machine equipped with 16 oxyacetylene torches cut the flanges (face plates) at speeds of 4500 mm/min.

The web and flange parts are moved by a manually operated magnetic overhead gantry crane service to the next station where a single operator performs fit up. The face plates are set down first. The magnetic gantry crane picks up the web, rotates it 90 degrees and lowers it in place over the face plate. Once the parts are fit up precisely by the operator, he then places a tack weld at the front end (both sides). The bars are then fed to (3) ESAB welding machines that automatically weld the webs to the flanges. The machines use induction heating on the top of web to compensate for the heat of welding at the bottom. Welding is by submerged arc fillet welding on both sides. An unmanned profile moving crane (TTS) moves the completed profiles to the cooling area. After a three hour cooling time, they are checked for accuracy including a check to ensure that **they have less than  $\pm 7$  mm out-of-straightness over 16 meter lengths.** Out of tolerance profiles are moved to another station for mechanical straightening. Finally, the profiles are moved to a station where the welded and ground areas are re-blasted and painted.

Odense Steel Shipyard also makes use of an Oxytechnic robot for cutting rolled T, I, and L profiles as well as flat bar. An oxyacetylene torch is used. The shape data to drive the robot is transferred from the HICADEC system after being post-processed for the specific machine. There is another N/C machine for performing simpler end cuts. A machine (apparently made by the Odense Steel Shipyard) mechanically removes primer from the edges of rolled shapes using steel brushes. Nesting of the profile parts is done by the PMS system utilizing part data obtained from HICADEC-H. A PC-based nesting tool is used.

### **C. 1.3 Small Parts Cutting**

The Odense steel facility has a new flexible cell for cutting small steel parts including brackets and stiffener transition pieces. Torben Andersen stated that this facility has turned out to be one of the key cost-saving systems implemented at the Odense shipyard. Scrap and remnant plates from the primary plate cutting operations are measured and their dimensions input daily into the PMS system inventory database. Small parts needed to support current production are nested on these plates in inventory and NC data for cutting these parts is generated. Two small NC ESAB burning machines each with six (6) oxyacetylene torch heads are used to cut these parts. The small parts cutting facility is considered a key just-in-time (JIT) fabrication cell - parts can be nested, cut, and delivered on 24 hours notice. Pieces are also welded into small assemblies in special jigs to facilitate optimum welding. It appears that this small parts cutting facility was developed to reduce material costs.

A PC-based program developed by Maersk Data is used for nesting the small parts and brackets cut in this facility. Unlike the main hull plate cutting, nesting is not done by block in this facility. Parts for multiple blocks are nested together in order to minimize scrap and plate handling.

### **C.1.4 Panel Line**

Marked and cut plates from the main hull plate cutting tables are moved by magnet crane to the panel line and positioned to within M1.5 mm. These plates are welded (welding speed of 2500 mm/min) to form panels which measure 16 meters wide by 24 meters long. Plate positioning is done using pin stops and the layout is checked for dimensions and squareness using laser theodolites. The plate blankets are welded on two side-by-side 16 meter wide panel lines. Submerged arc single-side welding of plates up to 26 mm (approximately 1 inch) in thickness is utilized using ESAB welding machines on TTS gantries. No brushing or other removal of the plate primer is done, the welding burns through this primer. The plates are forwarded to the next station where they are welded in 32 meter wide panels using portable, one-sided, track-directed submerged arc welding machine.

Panel line capacities were described as 1000 meters or weld/day, 15 panels/day, and 60,000 meters of weld/ship.

### **C.1.5 Flat Panel Assembly Welding**

The completed panels are rolled along a roller-wheel conveyor to a sub-assembly fit and tack station. Floors and transverse frames are positioned and tacked to a base panel using temporary fixtures or brackets. As appropriate to some sub-assemblies, the “base panel” may be selected to maximize subsequent welding efficiency of the sub-assembly. Floors and transverse frames are positioned in place by temporary fixtures or brackets. Longitudinal profiles are then slid (threaded) through the floor cutouts. The tolerances on these cutouts is all mm. The profiles are held in place by the tight fitting stiffener cutouts in the floors and/or transverse frames. At this point both the longitudinal and transverse frames are fitted and tack welded to the plate blanket, but not to one another. No tack welds are applied above the baseplate in order to keep flexibility for rolling along conveyor rollers without gouging and scoring associated with rigid assemblies supported by only two or three rollers. Stiffeners are clamped in position with magnetic clamping. Tack welding is performed by 3 semi-automatic welding machines. Dimensional accuracy is checked using the MONMOS system.

Fitted sub-assemblies are next rolled to the end of the roller-wheel conveyor for final fit-up and tack welding. Once completed, a tracked carrier slides under the assembly, lifts it and transports it across an aisle-way to the robotics welding station.

The robotic flat panel assembly welding station has a 32 x 24 x 6 meter sub-assembly size envelope in which it can weld. The workstation has headroom for 12 meter high assemblies, however the robots are limited to 6 meter of vertical travel. The station has 12 HIROBO robots manufactured by Hitachi Zosen suspended from overhead gantries. Fillets of up to 6 mm throat are welded utilizing these robots.

Approximately 40% of the (fillet) welding required to complete the sub-assembly is completed in the robotics cell. Some welding cannot be “reached” by the robotics and some is intentionally left undone (e.g. ends of profile-to-plate welds) to maintain flexibility for fit-up to adjacent sub-assemblies. Rule-based weld sequencing is used to control weld distortion. The capacity of this robotic cell was claimed to be 1000-1500 meters of fillet welds per day (60,000 meters per ship). The automation plan calls for 1 operator for 3 robots. We saw more than this ratio, however the cell has only been on-line 3 months.

The new flat panel assembly welding system was developed for the 4800 TEU vessel contract and utilizes robots purchased in 1991 with a new gantry and integrated control system. The parameters describing the flat panel assembly robotic welding facility are summarized in Table 4. The finite element method (FEM) deflection compensation method is not yet fully implemented, thus limiting the current operating range of this robotic welding station. The robot controllers use American software called

Cellworks. This software is linked to the planning system which is fed by HICADEC-H. Only one person processes the off-line robotic programming. Torben Andersen said that automated (i.e. macros) off-line programming integrated with 3-D CAD product models was a MUST and it just won't work any other way. Off-line simulation will never be effective in this environment according to Torben.

### **C. 1.6 Curved Hull Forming and Assemblies**

Hull plate forming is accomplished by traditional roll bending, impact bending, and line heating. Six (6) pin jig facilities were observed, one being part of the line heating facilities. The adjustments in pin heights are based on calculations from the **CAD/CAM system. The bases of assembly pin jigs can be tilted  $\pm 14$  degrees to keep** work surfaces level during various stages of assembly. 3-D theodolite checking systems are used to ensure dimensional accuracy.

A new curved shell block gantry 2-head robotics system (MOTOW robots) is used to complete much of the sub-assembly welding. The "AMROSE" technology is being used to specify robot motions in this (pilot project) assembly facility. AMROSE was described as utilizing enriched (NURBS?) mathematics to describe curved areas. This approach permits accurate motion specifications even in variable curvature 3-D applications. It also features some advanced collision avoidance software. The target for this curved hull robotic station is to complete an additional 20 percent of the assemblies welded by automated methods. If successful, this will increase the total from 70% (flat panel assemblies only) to 90% for the current 4800 TEU vessels. The parameters describing this system are summarized in Table 4 and the system is illustrated in Figure 7. The cutout tolerances for curved assemblies had to be increased from 1 mm to 2 mm to permit the profiles to be "threaded" through the tack-welded assemblies.

### **C. 1.7 Blast and Painting**

Odense has a long tradition of using painting halls. The surface quality produced in these facilities is claimed to be far superior. Currently, the shipyard has 11 blast and paint booths including 2 new ones just going into production. A SA-2Y2 sand blast is used and painting is completed except within about a foot of assembly joints. Currently, there are very little limitations regarding VOC levels but there is growing pressure to move to the use of water-based, low VOC paints.

### **C.1.8 Block Assembly**

Block divisions are determined during the design phase primarily by weight using the contract drawings as input. Manual sketches for each block showing assembly sequencing and shop routing are used to determine an initial work breakdown structure (WIN). This process, done manually today, is being moved to the PROMOS system.

The manufacturing WBS (part-assembly-block), including piece-part numbering for parts and assemblies have historically been completed using HICADEC. PROMOS is now being used by the Production Engineering Department for this WBS development. All parts are defined in this network, each having a uniquely defined piece-part number.

Vertical block seams to be welded in the drydock are protected by an enclosure running from the bilge to the main deck. Electro-gas welding was said to be used with a seam welder that was hidden from view by the enclosure.

## **C.4 OUTFITTING**

The shipyard does most of the outfitting installation and fabrication of pipe spools, small assemblies, railing, ladders, gratings, etc. They appear to use sub-contractors for most outfitting which does not involve straight-forward fabrication of steel. Even in the pipe fabrication area, surface treatments except simple oil bath or water jet are done by sub-contractors. Likewise, high pressure pipe fabrication requiring weldolets is also sub-contracted. Electrical installation is one of the few installation tasks generally done by sub-contractors.

### **C.2.1 Pipe Shops**

The pipe shop is organized very efficiently and driven by workshop information reports extracted from MAPSOS, the pipe production system which is integrated with the HICADEC-P system through an the INGRES SQL database. Vendor agreements require pipe and fitting vendors to keep re-stocking a small inventory of materials in the pipe shop from their inventories stored in close proximity to the shipyard. Typically re-stocking is done twice a week based on production planning documentation produced by the shipyard for the vendors. An OXYTECHNIC system has been implemented for handling incoming pipe.

Incoming pipe is based on 6 meter lengths of standard stock sizes. Special sizes can be input on the opposite side from the standard stock input bins. The pipe shop produces spools for every standard pipe size every eight (8) days. Consequently, the production planning allows eight days for spool production, with the exact schedule determined (“D-Planning”) by the pipe shop foreman. Pipe bending is used extensively for pipe up to 250 mm in diameter. Piping system use primarily bolted flange connections except for heating coils and steam systems which utilize welded joints.

The 200-250 mm and smaller pipe fabrication is highly mechanized in terms of material handling, bending, and welding. 6 meter pipe lengths are conveyed to the cutter and f~st cut to length as detailed in HICADEC-P and nested in the PROMOS software. Measurement is manual for short lengths and utilizing conveyor advance for long lengths. The advance calibration is checked weekly. Immediately following the cutting, long sections are conveyed to a grinder for weld preps. These pipes next are conveyed to a

automated flange welder. Ideally, both flanges are welded simultaneous (first chucked and tacked then double sided welding on both ends) prior to pipe bending. Exceptions are made where excess length is needed for clamping beyond a pipe bend, complex bending is required, or other non-standard conditions. Large pipe sizes, unusual fabrications (e.g. tees and/or stubs), or unusual (non-90 or 45) bends are handled in separate facilities. These fabrications are fitted in the pipe shop then removed to outside workstations for final welding. Each spool is tagged with a metal label produced by HICADEC-P.

Workshop information is produced from HICADEC-P (spool drawings) and MAPSOS (work orders, nesting, treatments and testing requirements). This information is produced on paper for use in the pipe shop. Cutting and bending processes are manually controlled. Cut lists are specially prepared for use in the cutting facility which contain only the necessary size, cut length, and marking information.

The day's production in the pipe shop is placed on carriers and moved outside to a staging area. Two workers sort the production according to the clean and coating needs. Except for some oil bath and high-pressure water cleaning, all surface prep and coating work is sent out to subcontractors. Spools are sent to one of the assembly halls for installation into piping subassemblies consisting of numerous spools and support structures.

### **C.2.2 Small Components**

Specialized shops are used to manufacture miscellaneous small assemblies by teams that develop skills and methods appropriate to a narrow range of "products". No foremen are employed in these shops, the teams decide how they will produce their products. Examples include hatch covers, ladders, brackets, handrail assemblies, small foundations, stairs, and gratings. Plate products cut to size and shape are "ordered" by these shops from the small parts cutting line in the steel fabrication facility.

New tools, methods, and/or equipment to facilitate the work in these shops are proposed by the shop teams and obtained in conjunction with revised pay schedules for the "products" of the shop. These tools and methods need not be sophisticated. For example, a simple robot welding facility was observed producing ladders. This welding robot is not product model-based, but rather its motion specification is based on "teach play back" of this highly repetitive process. This facility reduced cost by 66% over what was thought to be a highly productive manual process previously utilized.

The shipyard just initiated a limited duty shop allowing high skilled but older or partially disabled workers to do productive work. This shop produces lifting pads, machined parts, and other small weldments.

### **C.2.3 Outfitting Hall**

The main building hall constructs 3 deck high units up to 800 tons and up to 10,000 components per block. Blocks come into the facility blasted and painted except within one foot of the joints to connect with adjacent blocks. Emphasis is placed on scheduling nearly all hot work prior to this stage to maximize painting in the blast and paint facilities. Typical blocks spend 1-3 weeks in this hall depending on complexity.

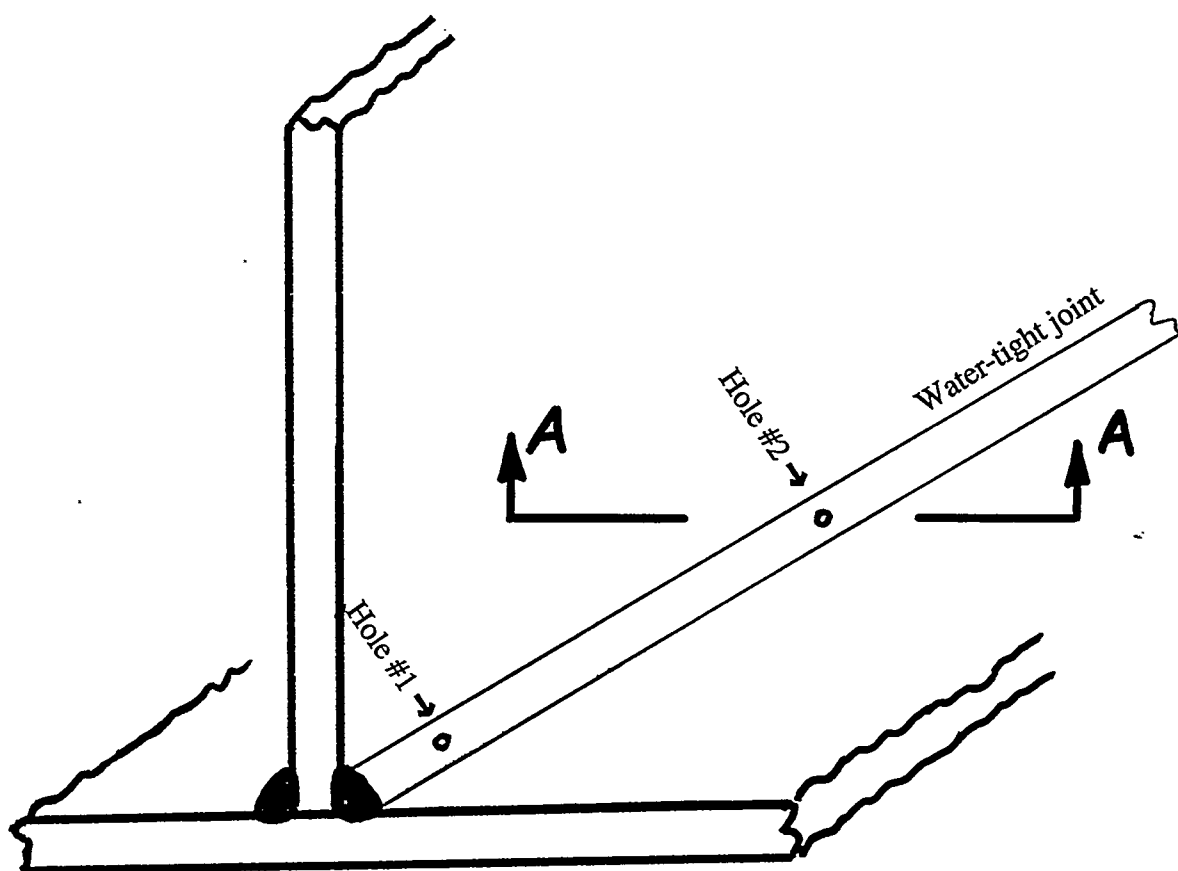
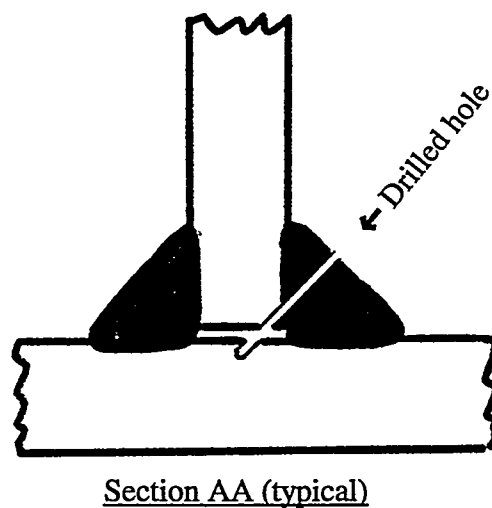
### **C.3 LEAK-TIGHT TEST**

Odense has developed and gotten approval to utilize a test method for verifying leak-tight welded joints prior to hydrostatic testing of completed tanks. This test used so that these joints can be tested and any necessary re-work of welds be accomplished during sub-assembly welding rather than during final assembly in the drydock or final outfitting dockside. Since leak-tight testing must be done prior to painting, this method also permits these joints to be painted when the block is painted. The method is valid for “oil tight” and “water tight” but not “smoke tight”. It is used primarily for ballast tanks. It was suggested that about 4+ hours is needed to test an entire block by this method.

The test configuration is illustrated in Figure 8. A small (5 mm) hole is drilled through a fillet weld on one side of the joint. A second hole is likewise drilled 2-3 meters away from the first hole in the same fillet weld. Soapy water is applied along the fillet welds on both sides of the joint. Compressed air (about 6 atm.) is injected through a nylon nozzle into the first hole and exhausted from the second hole. Assuming no bubbles are detected along either fillet weld, a leak-tight condition is verified. If injected air does not exhaust from the second hole, it is assumed that blockage exists between the holes and the hole spacing is reduced until the entire length of welded joint is adequately tested by exposure to compressed air.

Lloyd’s surveyors are familiar with this test method and agree to its use over more conventional testing. DNV and ABS have also indicated acceptance of this method.

FIGURE 8. LEAK-TIGHT TEST CONFIGURATION



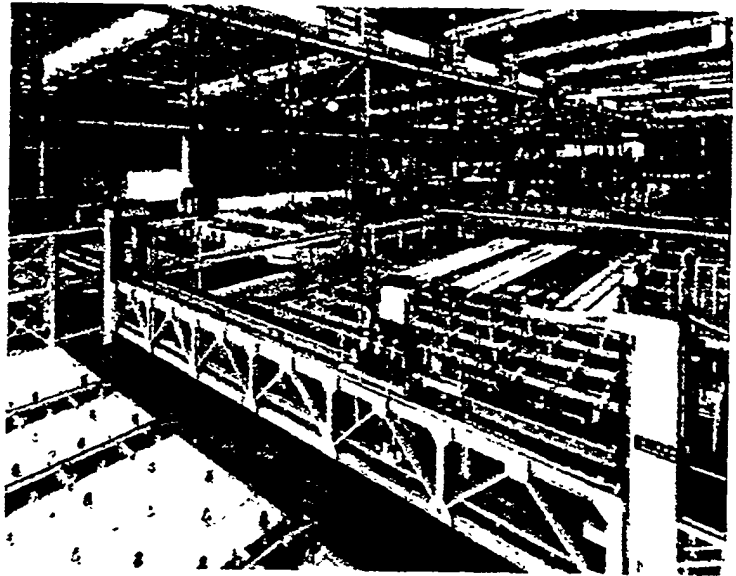


## Robots & Automatic Welding Machines of HITACHI ZOSEN Ariake Works

An innovative one-side welding process for plate joining that makes possible extra high speed welding 2.5 times faster than the traditional FCuB process with an excellent weld-quality.

This development was awarded a very authoritative prize from the Japan Society for the Promotion of Machine Industry in 1993, and furthermore "The Technology-Prize in 1995" from the Japan Welding Engineering Society.

The NH-HISAW is playing a role of the initial explosive to promote the remarkable speed-up of the whole assembly line of the Ariake Works.



HIROBO WR-L50 robots have been used in combination with "Robot-origin transfer units", which provide "eye" and "foot" functions, in the Egg-Box of hull structures. An advanced operation linkage technology between CAD/CAM and robots has realized a conversion from "Skill" to "Technology" in the shipyard.

A female operator is operating four sets of HIROBO simultaneously thus



taking full advantage of the advanced robot application technology aided by computers.

# Robots & Automatic Welding Machines of HITACHI ZOSEN Ariake Works

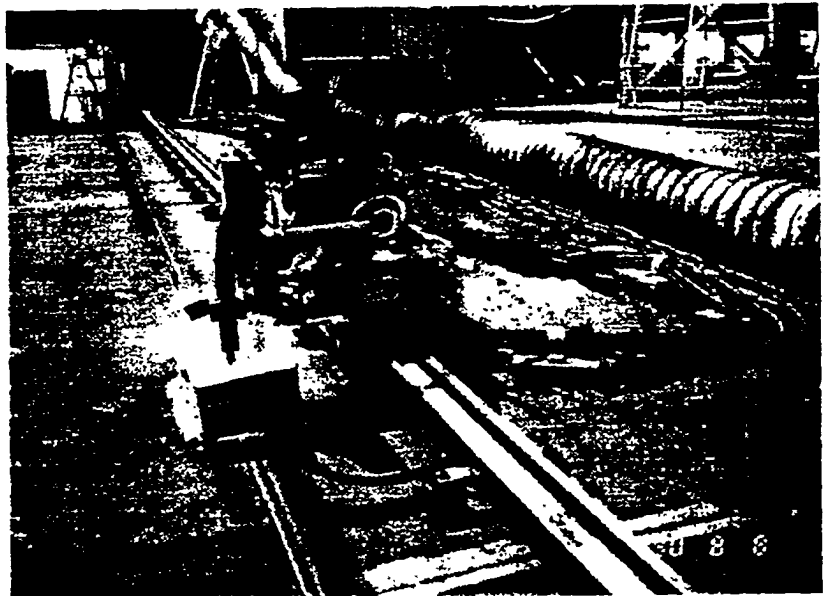
## NC Gantry Type Welding Robots with Twin-Torch

At the final stage of Cutting/  
Prefabrication conveyor line(Web  
Line), NC Gantry Type Welding  
Robots with Twin-Torch have  
been used and the role of them is  
to weld Stiffeners on the Web  
Plate including end-corner  
welding. Single female operator is  
simultaneously operating two  
robots using an advanced  
operation linkage technology  
between CAD/CAM and robots,  
and excellent high quality welds have been efficiently produced by the robots.



## Portable Self-Driving type Welding Robots(HIAUTO)

HIAUTO are portable self-driving  
type welding robots with  
simultaneous control functions  
over three axes motions and they  
have been applied to block-joints  
in the dock such as the Upper  
Deck and the Tank Top, etc. of  
double hull structure.  
The robots has a special root-gap  
adaptive control function thus  
difficult operation of the erection  
joints such as one-side multi-pass  
welding has been carried out easily with excellent quality.

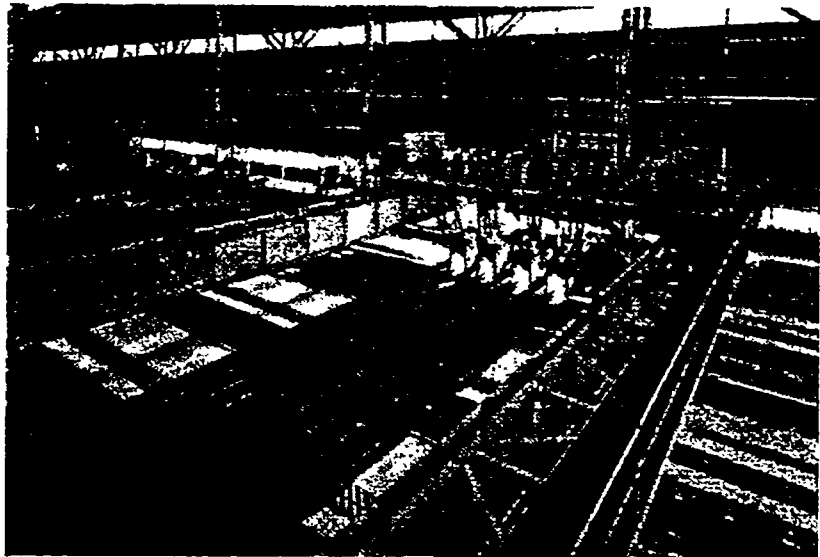


## Robots & Automatic Welding Machines of HITACHI ZOSEN Ariake Works

### Line Welder for Longitudinal Frames

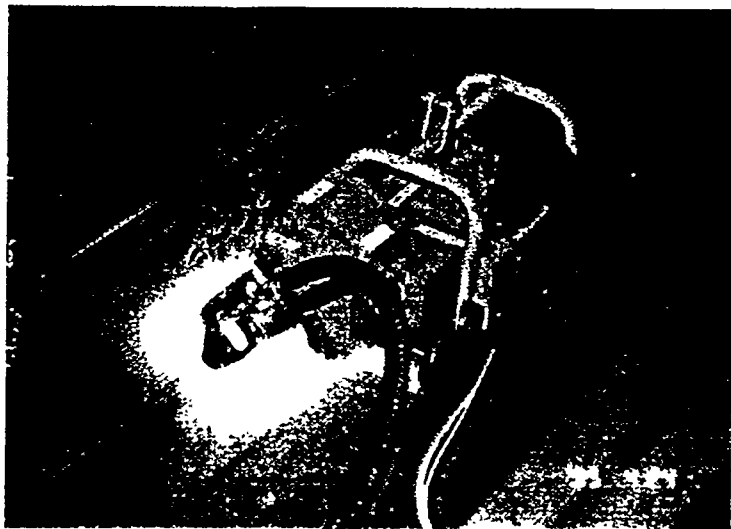
In the next stage of plate joining, a Line Welder has been used.

The equipment consists of a gantry type movable placer and ten welding carriages with twin-torch, for a total of 20 electrodes. Ten pieces of Longitudinal Frames can be welded on a skin plate simultaneously with the equipment, at a welding speed of about 50 cm/min..



### Self-driving type portable welding robot for curved longitudinal frames and curved shell plate

HICURVE is a self-driving type portable welding robot to weld the fillet joints between curved longitudinal frames and curved shell plate of the ship-hull. The fitting angle of the longitudinal frame, and the transverse inclination and longitudinal inclination of a joint are automatically detected by the sensors of robot. Depending on the signal of sensors, the robot automatically control the torch angle and the aiming point of wire, and simultaneously picks up the optimum welding parameters from the welding library in the robot-controller. HICURVE robots are producing high quality welds in lieu of highly skilled welders at the Fore & Aft Hull Assembly Stage.

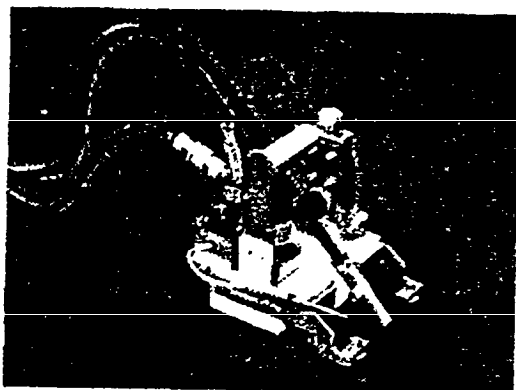


## Robots & Automatic Welding Machines of HITACHI ZOSEN Ariake Works

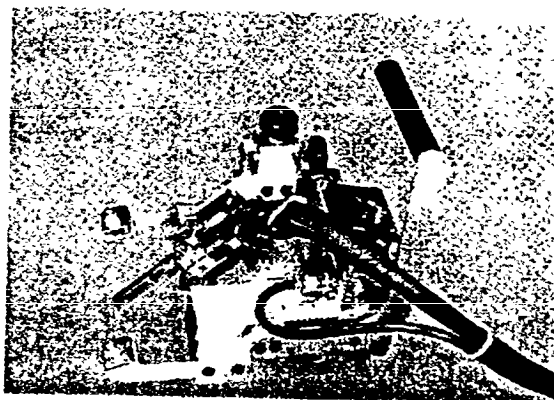


Number of machine : 132 sets  
(1995.April)

Automation of welding has been actively developed in all stages adding the own improvements to the various machines being on the market.



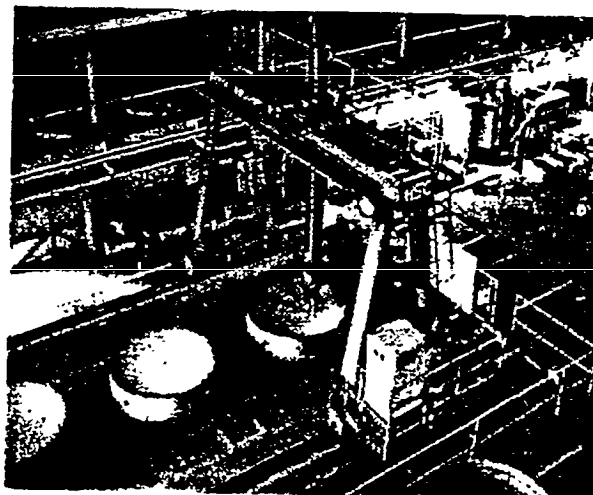
SUMI AUTO



WELHANDY

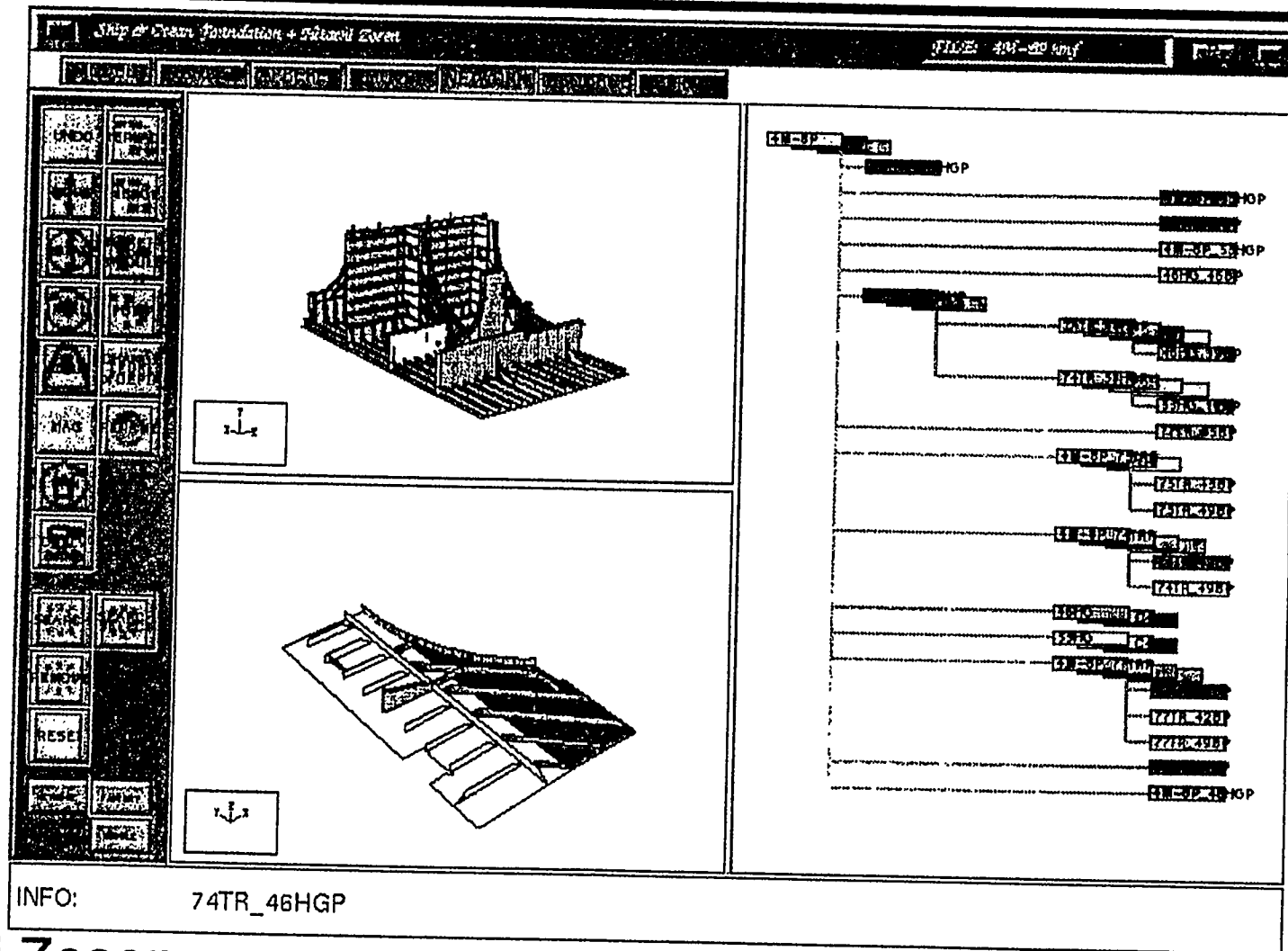
### NC Gantry Type Welding Robot mounting a HIROBO

A NC gantry type welding robot mounting a HIROBO WR-L50 has been utilized to the fabrication of various outfitting. Attached Photo. shows an example of application for the fabrication of Anti-explosion Hatch to be installed on the oil storage ship.





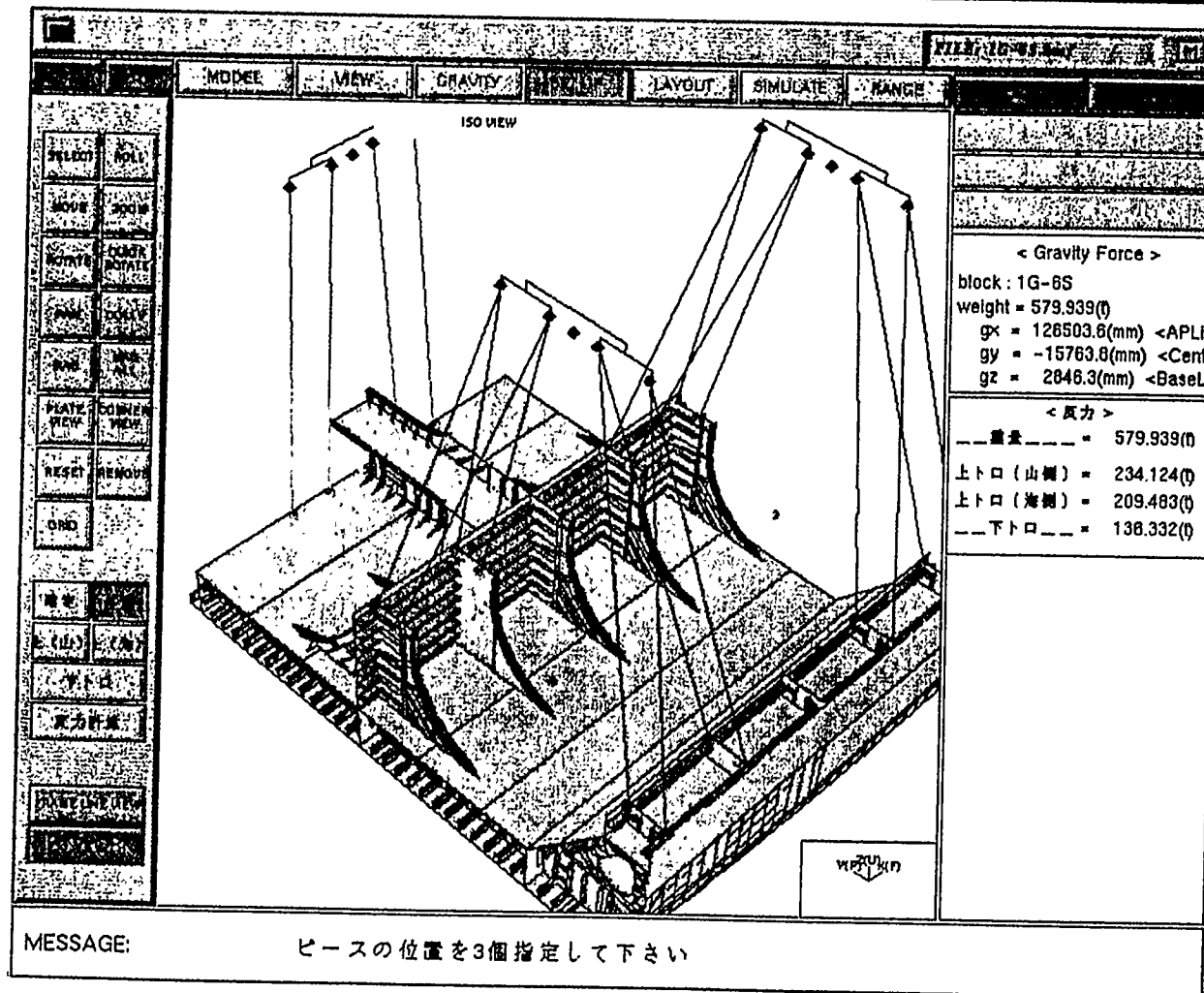
# NEED



Appendix E

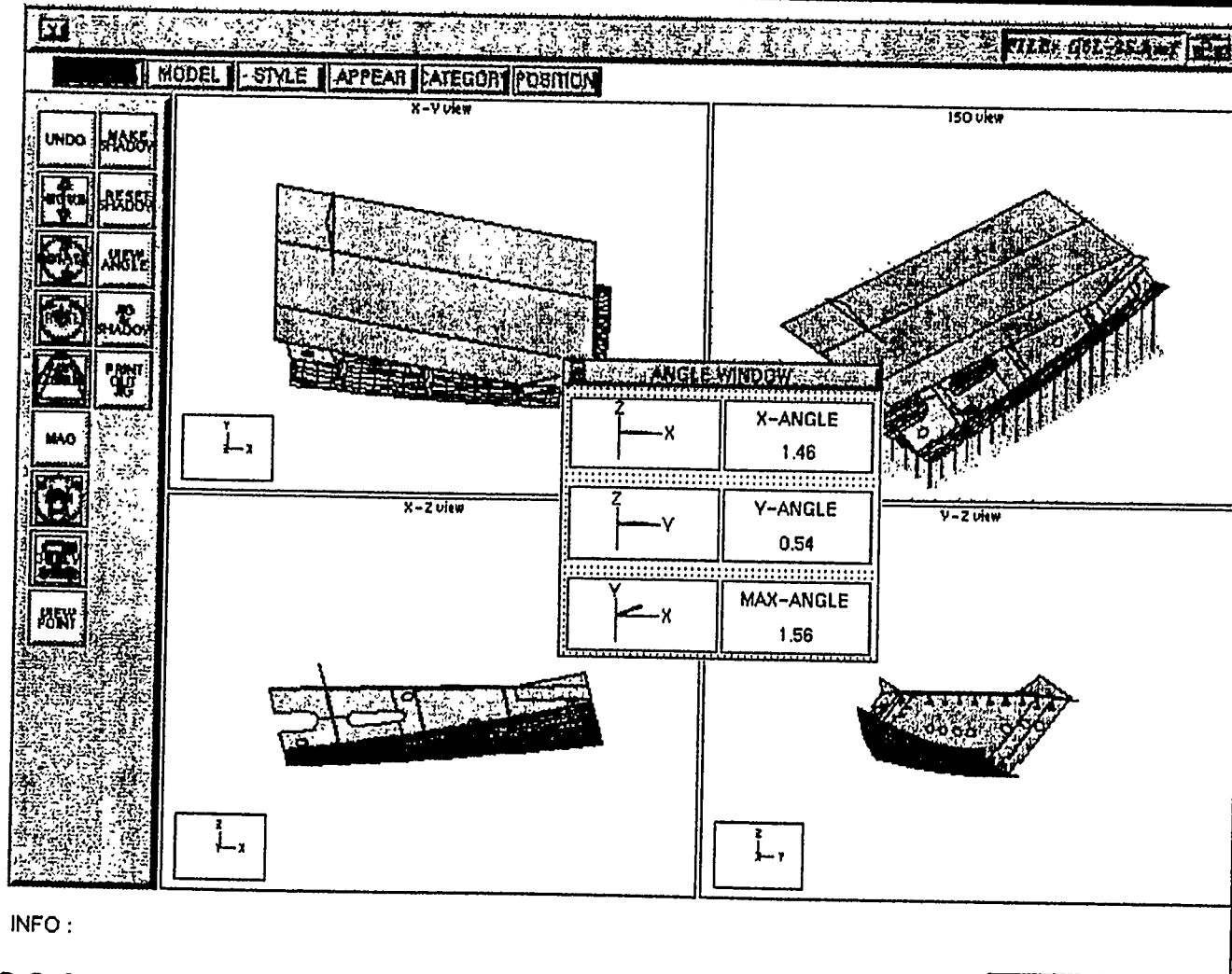
Hitachi Zosen

# LIPSS



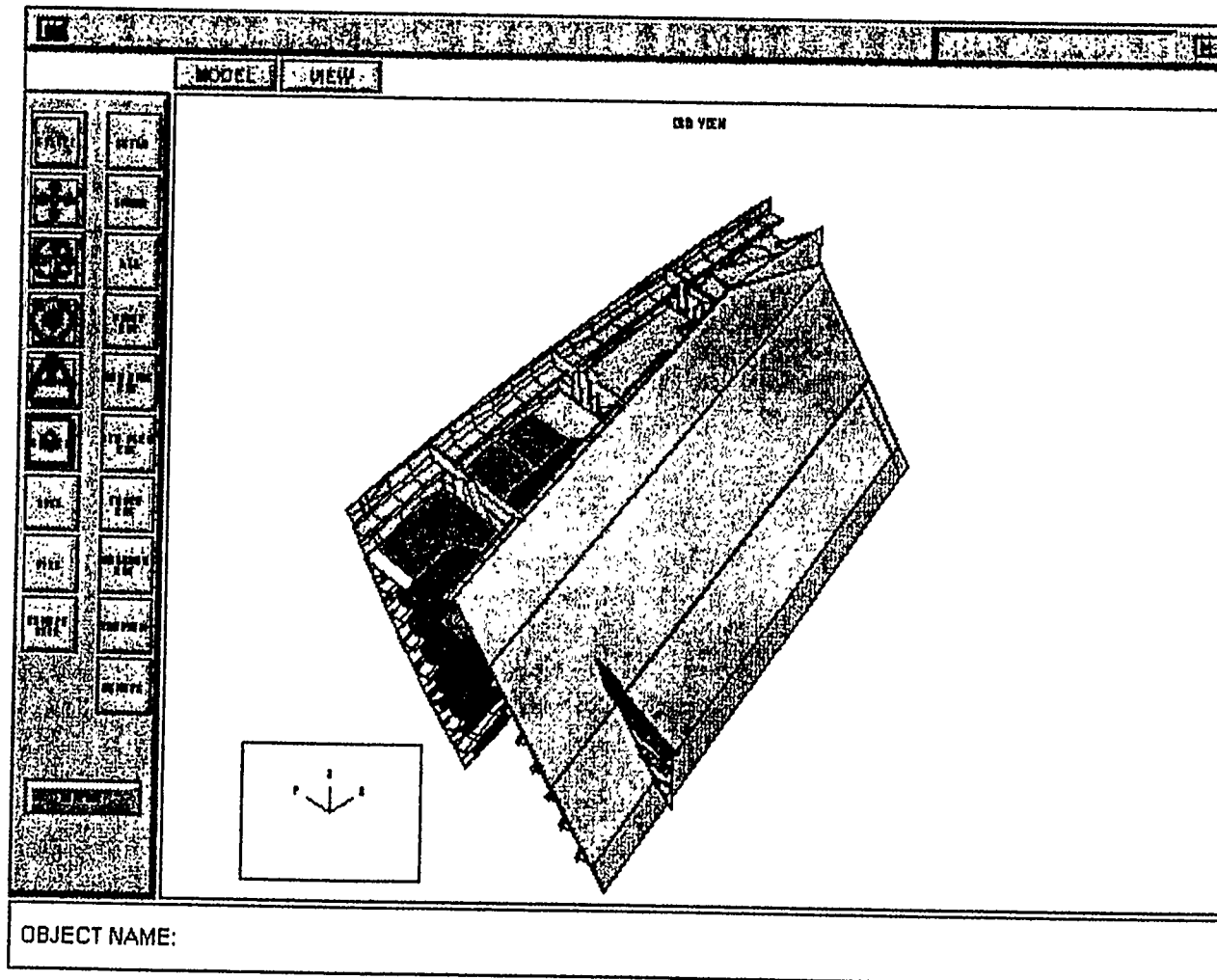
Hitachi Zosen

# JIG(Orientation Check)



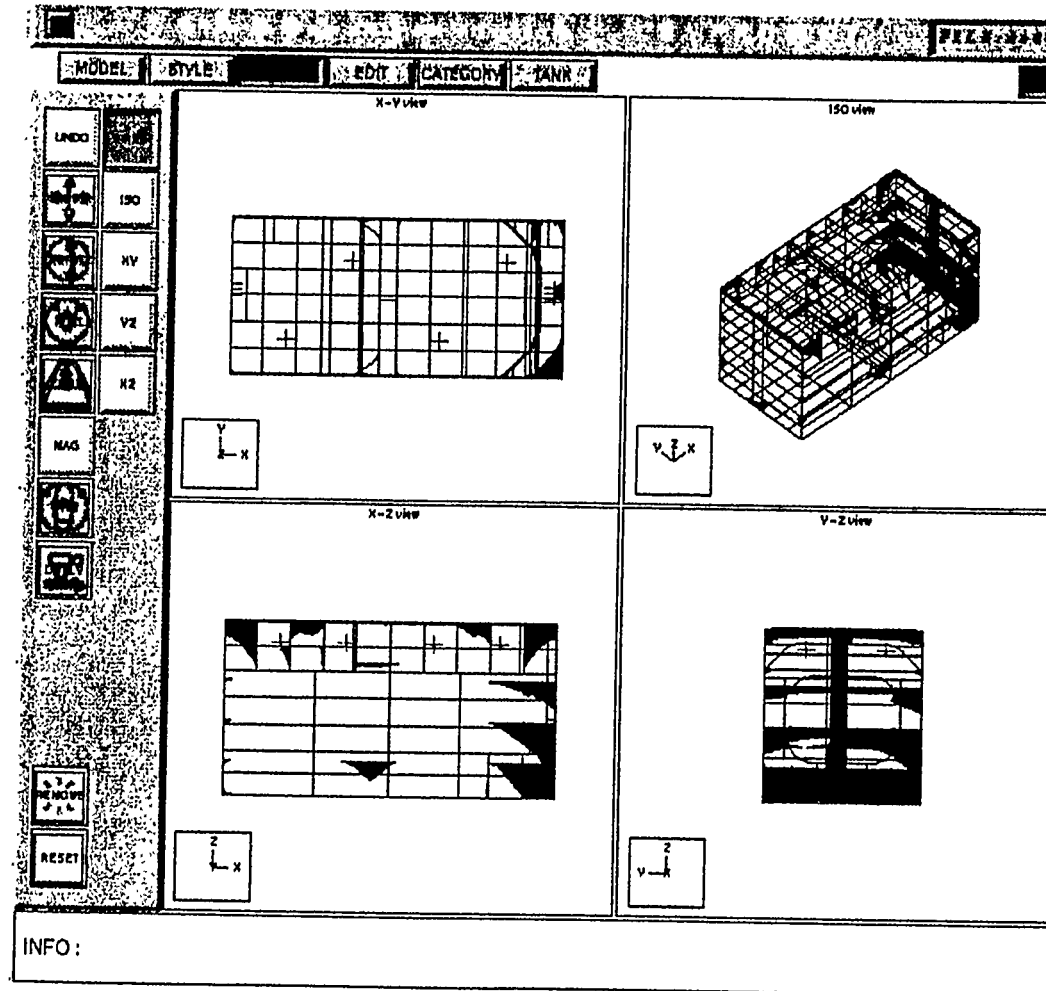
Hitachi Zosen

# TOPOS



Hitachi Zosen

# LASC



Hitachi Zosen



## Appendix F

# CAD/CAM/CIM Evaluation Host Yard Survey

### Design, Operations Management and General

Mainly Computer

Mix

Mainly Manual

☐ ☐ ☐

### Production Processes

Mainly Computer Automated or Generated

Mix

Mainly Manually Generated or Controlled

☐ ☐ ☐

**Conceptual/Preliminary Design:** The initial design stages for a new vessel, in which general characteristics and basic system requirements are defined.

Hull Structure and Outfitting

☒☐☐ Engineering analysis tools Odense

☒☐☐ Engineering analysis tools Hitachi

☒☐☐ Engineering analysis tools MHI

☐☒☐ Use of library of standard designs and parametric parts Odense

☐☒☐ Use of library of standard designs and parametric parts Hitachi

☐☐☒ Use of library of standard designs and parametric parts MHI

☐☒☐ Method of interfacing with applications outside of the design system (e.g., word processing, spread sheets, and material requirements) Odense

☒☐☐ Method of interfacing with applications outside of the design system (e.g., word processing, spread sheets, and material requirements) Hitachi

☐☒☐ Method of interfacing with applications outside of the design system (e.g., word processing, spread sheets, and material requirements) MHI

☐☒☐ Integration of system design with build strategy Odense

☐☒☐ Integration of system design with build strategy Hitachi

☐☒☐ Integration of system design with build strategy MHI

☒☐☐ Weights and centers calculations Odense

☒☐☐ Weights and centers calculations Hitachi

☒☐☐ Weights and centers calculations MHI

☐☒☐ Cost estimation for tendering Odense

☒☐☐ Cost estimation for tendering Hitachi

☒☐☐ Cost estimation for tendering MHI

☒☐☐ Hull form design, including fairing Odense

☒☐☐ Hull form design, including fairing Hitachi

☒☐☐ Hull form design, including fairing MHI

☐☒☐ Classification requirements Odense

☒☐☐ Classification requirements Hitachi

☒☐☐ Classification requirements MHI

☒☐☐ Compartmentation. Odense

☒☐☐ Compartmentation. Hitachi

☒☐☐ Compartmentation. MHI

**Functional Design:** The second stage of ship design. Primary structure scantlings and compartment layout are defined in functional design, along with system diagrams for distributed systems. Primary space arrangements (machinery spaces, cargo and handling layouts, etc.) are also developed during functional design. For the purposes of this evaluation, functional design also includes "transition" design, in which initial design and outfitting zones are defined.

**Hull Structure and Outfitting**

☒☐☐ Development of structural arrangement and design including block and assembly breaks

Odense

☒☐☐ Development of structural arrangement and design including block and assembly breaks

Hitachi

☐☐☒ Development of structural arrangement and design including block and assembly breaks

MHI

☒☐☐ Engineering analysis tools Odense

☒☐☐ Engineering analysis tools Hitachi

☒☐☐ Engineering analysis tools MHI

☐☒☐ Use of specifications Odense

☒☐☐ Use of specifications Hitachi

☐☒☐ Use of specifications MHI

☒☐☐ Use of catalog of standard parts Odense

☒☐☐ Use of catalog of standard parts Hitachi

☐☒☐ Use of catalog of standard parts MHI

☐☒☐ Optimization of hull structural design to manufacturing facilities Odense

☐☒☐ Optimization of hull structural design to manufacturing facilities Hitachi

☐☐☒ Optimization of hull structural design to manufacturing facilities MHI

☒☐☐ Associativity among discipline areas such as structure, hull and piping Odense

☐☒☐ Associativity among discipline areas such as structure, hull and piping Hitachi

☐☒☐ Associativity among discipline areas such as structure, hull and piping MHI

☒☐☐ Parametric parts definitions and parametric features (endcuts, cutouts, and connections)

Odense

☒☐☐ Parametric parts definitions and parametric features (endcuts, cutouts, and connections)

Hitachi

☒☐☐ Parametric parts definitions and parametric features (endcuts, cutouts, and connections)

MHI

☒☐☐ Material definitions Odense

☒☐☐ Material definitions Hitachi

☐☐☒ Material definitions MHI

☐☒☐ Refinement of system design with respect to build strategy Odense

☐☐☐ Refinement of system design with respect to build strategy Hitachi

☐☒☐ Refinement of system design with respect to build strategy MHI

#### Interim Products

- ☐☐☐ Finalization of interim products to manufacturing facilities Odense
- ☒☐☐ Finalization of interim products to manufacturing facilities Hitachi
- ☐☐☒ Finalization of interim products to manufacturing facilities MHI

- ☐☐☒ Refinement of build strategy Odense
- ☒☐☐ Refinement of build strategy Hitachi
- ☐☐☒ Refinement of build strategy MHI

**Detailed Design:** The design stage in which the detailed structural and systems design occurs; detailed calculations, systems integration and interference checking are performed; and the detailed product model is developed. For the purposes of this evaluation, detail design also includes the development of production-ready documentation, including bills of materials, fabrication and assembly level drawings, and sketches.

#### Hull Structure and Outfitting

- ☒☐☐ Engineering analysis tools Odense
- ☒☐☐ Engineering analysis tools Hitachi
- ☒☐☐ Engineering analysis tools MHI

- ☒☐☐ Interference checking (includes structure and outfitting) Odense
- ☐☒☐ Interference checking (includes structure and outfitting) Hitachi
- ☐☒☐ Interference checking (includes structure and outfitting) MHI

- ☒☐☐ Integration with outfitting Odense
- ☐☒☐ Integration with outfitting Hitachi
- ☐☒☐ Integration with outfitting MHI

- ☒☐☐ Development of production-ready documentation Odense
- ☒☐☐ Development of production-ready documentation Hitachi
- ☒☐☐ Development of production-ready documentation MHI

- ☒☐☐ Design for fabrication assembly and erection Odense
- ☒☐☐ Design for fabrication assembly and erection Hitachi
- ☒☐☐ Design for fabrication assembly and erection MHI

- ☒☐☐ Linkage to fabrication assembly and erection (method of transferring the product information to the process) Odense
- ☒☐☐ Linkage to fabrication assembly and erection (method of transferring the product information to the process) Hitachi
- ☒☐☐ Linkage to fabrication assembly and erection (method of transferring the product information to the process) MHI

- ☒☐☐ Linkage to bill of material and procurement Odense
- ☒☐☐ Linkage to bill of material and procurement Hitachi
- ☒☐☐ Linkage to bill of material and procurement MHI

- ☐☒☐ Weld design (e.g., weld preparation, weld procedures) Odense
- ☒☐☐ Weld design (e.g., weld preparation, weld procedures) Hitachi
- ☐☐☒ Weld design (e.g., weld preparation, weld procedures) MHI

- ☒☐☐ Volume and area calculations Odense

- ☒☐☐ Volume and area calculations Hitachi
- ☒☐☐ Volume and area calculations MHI
- ☒☐☐ Incorporation of standards (e.g., parts, plate and shape catalogue) Odense
- ☒☐☐ Incorporation of standards (e.g., parts, plate and shape catalogue) Hitachi
- ☒☐☐ Incorporation of standards (e.g., parts, plate and shape catalogue) MHI
- ☒☐☐ Parametric parts definition Odense
- ☒☐☐ Parametric parts definition Hitachi
- ☒☐☐ Parametric parts definition MHI
- ☐☒☐ Painting specification development Odense
- ☒☐☐ Painting specification development Hitachi
- ☐☐☒ Painting specification development MHI

#### Interim Products

- ☒☐☐ Engineering analysis tools Odense
- ☒☐☐ Engineering analysis tools Hitachi
- ☐☐☒ Engineering analysis tools MHI
- ☒☐☐ Incorporation of standards Odense
- ☒☐☐ Incorporation of standards Hitachi
- ☐☐☒ Incorporation of standards MHI
- ☒☐☐ Development of production-ready documentation Odense
- ☒☐☐ Development of production-ready documentation Hitachi
- ☒☐☐ Development of production-ready documentation MHI
- ☒☐☐ Definition of interim products Odense
- ☒☐☐ Definition of interim products Hitachi
- ☐☐☒ Definition of interim products MHI
- ☒☐☐ Dimensioning Odense
- ☒☐☐ Dimensioning Hitachi
- ☐☐☒ Dimensioning MHI
- ☐☐☐ Dimensional tolerances including adjustments to part dimensions made in design based on as-built subassembly dimensional measurements Odense
- ☒☐☐ Dimensional tolerances including adjustments to part dimensions made in design based on as-built subassembly dimensional measurements Hitachi
- ☒☐☐ Dimensional tolerances including adjustments to part dimensions made in design based on as-built subassembly dimensional measurements MHI

**Fabrication Processes:** Includes all processes associated with part fabrication, including leveling/straightening, marking, cutting, bending and forming, machining process, casting and forging.

#### Structure

- ☒☐☐ Structural plate and shape cutting processes Odense
- ☒☐☐ Structural plate and shape cutting processes Hitachi
- ☒☐☐ Structural plate and shape cutting processes MHI
- ☐☒☐ Structural plate and shape forming processes Odense
- ☒☐☐ Structural plate and shape forming processes Hitachi

- ☐ ☒ ☐ Structural plate and shape forming processes MHI
- ☒ ☐ ☐ Documentation of production processes (e.g., procedures manuals, process flow diagrams, imbedded applications) Odense
- ☒ ☐ ☐ Documentation of production processes (e.g., procedures manuals, process flow diagrams, imbedded applications) Hitachi
- ☐ ☐ ☒ Documentation of production processes (e.g., procedures manuals, process flow diagrams, imbedded applications) MHI
- ☒ ☐ ☐ Information links to cutting, forming, casting and fabrication work centers (including information feedback) Odense
- ☒ ☐ ☐ Information links to cutting, forming, casting and fabrication work centers (including information feedback) Hitachi
- ☐ ☒ ☐ Information links to cutting, forming, casting and fabrication work centers (including information feedback) MHI
- ☒ ☐ ☐ Piece and part labeling (Information links to the shop regarding WL, BTK, FRAME reference marking for ship locations; edge beveling; piece ID, material ID annotation; reference lines for welded structure stiffeners and brackets) Odense
- ☒ ☐ ☐ Piece and part labeling (Information links to the shop regarding WL, BTK, FRAME reference marking for ship locations; edge beveling; piece ID, material ID annotation; reference lines for welded structure stiffeners and brackets) Hitachi
- ☒ ☐ ☐ Piece and part labeling (Information links to the shop regarding WL, BTK, FRAME reference marking for ship locations; edge beveling; piece ID, material ID annotation; reference lines for welded structure stiffeners and brackets) MHI
- ☐ ☒ ☐ Error detection and handling Odense
- ☐ ☐ ☒ Error detection and handling Hitachi
- ☐ ☐ ☒ Error detection and handling MHI
- ☐ ☒ ☐ Process and product quality checks Odense
- ☐ ☐ ☒ Process and product quality checks Hitachi
- ☐ ☐ ☒ Process and product quality checks MHI

#### Outfitting

- ☒ ☐ ☐ Documentation of production processes (e.g., procedures manuals, process flow diagrams, imbedded applications) Odense
- ☒ ☐ ☐ Documentation of production processes (e.g., procedures manuals, process flow diagrams, imbedded applications) Hitachi
- ☐ ☐ ☒ Documentation of production processes (e.g., procedures manuals, process flow diagrams, imbedded applications) MHI

- ☒ ☐ ☐ Information links to cutting and forming work centers (including information feedback)
- Odense
- ☒ ☐ ☐ Information links to cutting and forming work centers (including information feedback)
- Hitachi
- ☒ ☐ ☐ Information links to cutting and forming work centers (including information feedback)
- MHI

- ☐ ☒ ☐ Error detection and handling Odense
- ☐ ☐ ☒ Error detection and handling Hitachi
- ☐ ☐ ☒ Error detection and handling MHI

- ☐ ☒ ☐ Process and product quality checks Odense

- ☐☐☒ Process and product quality checks Hitachi  
☐☐☒ Process and product quality checks MHI
- ☒☐☐ Creation of CNC programs in the machine shop Odense  
☐☐☐ Creation of CNC programs in the machine shop Hitachi  
☒☐☐ Creation of CNC programs in the machine shop MHI
- ☒☐☐ Creating path and/or process programs for NC-controlled machines or robotic work cells  
 Odense  
☒☐☐ Creating path and/or process programs for NC-controlled machines or robotic work cells  
 Hitachi  
☒☐☐ Creating path and/or process programs for NC-controlled machines or robotic work cells  
 MHI
- ☒☐☐ Piping cutting and bending Odense  
☒☐☐ Piping cutting and bending Hitachi  
☒☐☐ Piping cutting and bending MHI
- ☒☐☐ Ventilation cutting and forming Odense  
☐☐☐ Ventilation cutting and forming Hitachi  
☐☐☒ Ventilation cutting and forming MHI
- ☒☐☐ Electrical cable cutting and terminations Odense  
☒☐☐ Electrical cable cutting and terminations Hitachi  
☐☐☒ Electrical cable cutting and terminations MHI
- Interim Products**  
☒☐☐ Development of production instructions used in the fabrication of interim products, including nesting Odense  
☒☐☐ Development of production instructions used in the fabrication of interim products, including nesting Hitachi  
☐☒☐ Development of production instructions used in the fabrication of interim products, including nesting MHI
- ☒☐☐ Simulation of fabrication sequences Odense  
☒☐☐ Simulation of fabrication sequences Hitachi  
☐☐☒ Simulation of fabrication sequences MHI

**Joining and Assembly Processes:** Includes all types and stages of joining and assembly, all types of welding and other thermal joining methods, mechanical joining methods and adhesives. Stages include subassembly, assembly, block erection and post erection installations.

#### Structure

- ☒☐☐ Creation of NC programs. Odense  
☒☐☐ Creation of NC programs. Hitachi  
☒☐☐ Creation of NC programs. MHI
- ☒☐☐ Automated subassembly/assembly processes (reprogrammable robot manipulators, dedicated NC-controlled machines, PLC-controlled processes on automated / manual positioners) Odense  
☒☐☐ Automated subassembly/assembly processes (reprogrammable robot manipulators, dedicated NC-controlled machines, PLC-controlled processes on automated / manual positioners) Hitachi

- ☐ ☒ ☐ Automated subassembly/assembly processes (reprogrammable robot manipulators, dedicated NC-controlled machines, PLC-controlled processes on automated / manual positioners) MHI
- ☒ ☐ ☐ Programmable welding stations and robotic welding machines Odense
- ☒ ☐ ☐ Programmable welding stations and robotic welding machines Hitachi
- ☐ ☒ ☐ Programmable welding stations and robotic welding machines MHI
- ☒ ☐ ☐ Locations marking for welded attachments Odense
- ☒ ☐ ☐ Locations marking for welded attachments Hitachi
- ☒ ☐ ☐ Locations marking for welded attachments MHI
- ☒ ☐ ☐ Structural welding methodology (e.g., at welding stations, with portable robotics, use of sensors, off-line programming) Odense
- ☒ ☐ ☐ Structural welding methodology (e.g., at welding stations, with portable robotics, use of sensors, off-line programming) Hitachi
- ☐ ☒ ☐ Structural welding methodology (e.g., at welding stations, with portable robotics, use of sensors, off-line programming) MHI
- ☐ ☒ ☐ Welding optimization (e.g., minimize welding, maximize automation, minimize cost)
- Odense
- ☐ ☒ ☐ Welding optimization (e.g., minimize welding, maximize automation, minimize cost)
- Hitachi
- ☐ ☐ ☒ Welding optimization (e.g., minimize welding, maximize automation, minimize cost)
- MHI
- ☐ ☒ ☐ Definition of fit-up tolerances Odense
- ☒ ☐ ☐ Definition of fit-up tolerances Hitachi
- ☐ ☐ ☒ Definition of fit-up tolerances MHI
- ☒ ☐ ☐ Marking locations for welded attachments Odense
- ☒ ☐ ☐ Marking locations for welded attachments Hitachi
- ☒ ☐ ☐ Marking locations for welded attachments MHI
- ☐ ☒ ☐ Control of welding process parameters to minimize weld shrinkage and distortions
- Odense
- ☐ ☒ ☐ Control of welding process parameters to minimize weld shrinkage and distortions
- Hitachi
- ☐ ☐ ☒ Control of welding process parameters to minimize weld shrinkage and distortions MHI
- ☒ ☐ ☐ Programming for automated processes Odense
- ☒ ☐ ☐ Programming for automated processes Hitachi
- ☒ ☐ ☐ Programming for automated processes MHI
- ☒ ☐ ☐ Sensors (e.g. position) employed with automated welding Odense
- ☒ ☐ ☐ Sensors (e.g. position) employed with automated welding Hitachi
- ☐ ☒ ☐ Sensors (e.g. position) employed with automated welding MHI
- Outfitting
- ☒ ☐ ☐ Creation of NC programs. Odense
- ☒ ☐ ☐ Creation of NC programs. Hitachi
- ☒ ☐ ☐ Creation of NC programs. MHI

- ☒☐☐ Automated subassembly/assembly processes (reprogrammable robot manipulators, dedicated NC-controlled machines, PLC-controlled processes on automated / manual positioners) Odense
- ☒☐☐ Automated subassembly/assembly processes (reprogrammable robot manipulators, dedicated NC-controlled machines, PLC-controlled processes on automated / manual positioners) Hitachi
- ☒☐☐ Automated subassembly/assembly processes (reprogrammable robot manipulators, dedicated NC-controlled machines, PLC-controlled processes on automated / manual positioners) MHI

- ☒☐☐ Design and development of automated machines, processes and cells Odense
- ☐☐☐ Design and development of automated machines, processes and cells Hitachi
- ☐☐☒ Design and development of automated machines, processes and cells MHI

- ☐☒☐ Welding processes employed Odense
- ☐☒☐ Welding processes employed Hitachi
- ☐☒☐ Welding processes employed MHI

#### Interim Products

- ☐☒☐ Definition of fit-up tolerances for block assembly joints Odense
- ☒☐☐ Definition of fit-up tolerances for block assembly joints Hitachi
- ☐☐☒ Definition of fit-up tolerances for block assembly joints MHI
- ☒☐☐ Simulation and optimization of assembly and erection sequences Odense
- ☒☐☐ Simulation and optimization of assembly and erection sequences Hitachi
- ☐☐☒ Simulation and optimization of assembly and erection sequences MHI
- ☒☐☐ Subassembly/assembly processes (e.g., reprogrammable robot manipulators, dedicated NC-controlled machines, PLC-controlled processes) Odense
- ☒☐☐ Subassembly/assembly processes (e.g., reprogrammable robot manipulators, dedicated NC-controlled machines, PLC-controlled processes) Hitachi
- ☐☐☐ Subassembly/assembly processes (e.g., reprogrammable robot manipulators, dedicated NC-controlled machines, PLC-controlled processes) MHI

**Surface Treatment and Coating:** Includes all preparatory and finish work. Pre-production priming, blasting and cleaning methods (sand, shot, water, solvents), residue collection and cleanup, painting, finish painting and part painting are all considered.

#### Structure

- ☐☐☒ Cleaning and surface preparation Odense
- ☐☐☒ Cleaning and surface preparation Hitachi
- ☐☐☒ Cleaning and surface preparation MHI
- ☐☐☒ Painting Odense
- ☐☐☒ Painting Hitachi
- ☐☒☐ Painting MHI
- ☐☐☒ Process adjustments based on manual inspections and/or sensor indications (i.e. "closed loop process control) Odense

☐☐☒ Process adjustments based on manual inspections and/or sensor indications (i.e. "closed loop process control) Hitachi

☐☐☒ Process adjustments based on manual inspections and/or sensor indications (i.e. "closed loop process control) MHI

☐☐☒ Quality assurance (e.g., surface cleanliness, paint thickness, paint quality, cure) Odense

☐☐☒ Quality assurance (e.g., surface cleanliness, paint thickness, paint quality, cure) Hitachi

☐☐☒ Quality assurance (e.g., surface cleanliness, paint thickness, paint quality, cure) MHI

#### Outfitting

☐☐☒ Cleaning and surface preparation Odense

☐☐☒ Cleaning and surface preparation Hitachi

☐☐☒ Cleaning and surface preparation MHI

☐☐☒ Painting Odense

☐☐☒ Painting Hitachi

☐☐☒ Painting MHI

☐☐☒ Process adjustments based on manual inspections and/or sensor indications Odense

☐☐☒ Process adjustments based on manual inspections and/or sensor indications Hitachi

☐☐☒ Process adjustments based on manual inspections and/or sensor indications MHI

☐☐☒ Quality assurance (e.g., surface cleanliness, paint thickness, paint quality, cure) Odense

☐☐☒ Quality assurance (e.g., surface cleanliness, paint thickness, paint quality, cure) Hitachi

☐☐☒ Quality assurance (e.g., surface cleanliness, paint thickness, paint quality, cure) MHI

#### Interim Products

☐☐☒ Planning and assessment of painting processes for interim products Odense

☐☐☒ Planning and assessment of painting processes for interim products Hitachi

☐☐☒ Planning and assessment of painting processes for interim products MHI

**Material Control:** Incorporates all aspects of material tagging for identification, moving, kitting, palletizing, storing and disposal. Includes both hardware and software used to support material handling and tracking issues.

#### Structure

☒☐☐ Generation of pick lists; material marshaling and kitting; and material tracking Odense

☒☐☐ Generation of pick lists; material marshaling and kitting; and material tracking Hitachi

☐☒☐ Generation of pick lists; material marshaling and kitting; and material tracking MHI

☒☐☐ Documentation of processes (e.g., manuals, imbedded software) Odense

☒☐☐ Documentation of processes (e.g., manuals, imbedded software) Hitachi

☐☐☒ Documentation of processes (e.g., manuals, imbedded software) MHI

☒☐☐ Piece/parts tracking through fabrication and assembly Odense

☒☐☐ Piece/parts tracking through fabrication and assembly Hitachi

☐☒☐ Piece/parts tracking through fabrication and assembly MHI

☐☐☐ Communication of staging and palletizing requirements to suppliers Odense

☒☐☐ Communication of staging and palletizing requirements to suppliers Hitachi

☐☒☐ Communication of staging and palletizing requirements to suppliers MHI

☐☐☐ Supplier staging and palletizing of material Odense

☒☐☐ Supplier staging and palletizing of material Hitachi

☐☐☒ Supplier staging and palletizing of material MHI

#### Outfitting

☒☐☐ Generation of pick lists; material marshaling and kitting; and material tracking Odense

☒☐☐ Generation of pick lists; material marshaling and kitting; and material tracking Hitachi

☐☒☐ Generation of pick lists; material marshaling and kitting; and material tracking MHI

☒☐☐ Documentation of processes (e.g., manuals, imbedded software) Odense

☒☐☐ Documentation of processes (e.g., manuals, imbedded software) Hitachi

☐☐☒ Documentation of processes (e.g., manuals, imbedded software) MHI

☒☐☐ Development of routing information Odense

☒☐☐ Development of routing information Hitachi

☐☐☒ Development of routing information MHI

☒☐☐ Piece/parts tracking through fabrication and assembly Odense

☒☐☐ Piece/parts tracking through fabrication and assembly Hitachi

☐☐☒ Piece/parts tracking through fabrication and assembly MHI

☐☐☐ Communication of staging and palletizing requirements to suppliers Odense

☒☐☐ Communication of staging and palletizing requirements to suppliers Hitachi

☐☐☒ Communication of staging and palletizing requirements to suppliers MHI

☐☐☐ Supplier staging and palletizing of material Odense

☒☐☐ Supplier staging and palletizing of material Hitachi

☐☐☒ Supplier staging and palletizing of material MHI

#### Interim Products Odense

☐☐☐ Documentation of assembly and subassembly movement Odense

☒☐☐ Documentation of assembly and subassembly movement Hitachi

☐☒☐ Documentation of assembly and subassembly movement MHI

☐☐☐ Handling and staging of in-process and completed parts Odense

☒☐☐ Handling and staging of in-process and completed parts Hitachi

☐☒☐ Handling and staging of in-process and completed parts MHI

**Testing/Inspection:** Includes the areas of weld inspections by dye penetrant and other NDT means, visual and optical inspections, pipe hydro test, ventilation pressure drop tests, compartment tightness and strength tests, compartment completion inspections, and grounding and EMI tests.

#### Structure

☐☐☒ Welding inspection Odense

☐☐☒ Welding inspection Hitachi

☐☐☒ Welding inspection MHI

☐☐☒ Compartment tightness and strength tests Odense

☐☐☒ Compartment tightness and strength tests Hitachi

☐☐☒ Compartment tightness and strength tests MHI

☐☐☒ Compartment completion inspections Odense

☐☐☒ Compartment completion inspections Hitachi

☐☐☒ Compartment completion inspections MHI

**Outfitting Hitachi**

☐☐☒ Machinery inspections and tests Hitachi

☐☐☒ Machinery inspections and tests Odense

☐☐☒ Machinery inspections and tests MHI

☐☐☒ Pipe hydro tests Hitachi

☐☐☒ Pipe hydro tests Odense

☐☐☒ Pipe hydro tests MHI

☐☐☒ Electrical tests Hitachi

☐☐☒ Electrical tests Odense

☐☐☒ Electrical tests MHI

☐☐☒ Compartment completion inspections Hitachi

☐☐☒ Compartment completion inspections Odense

☐☐☒ Compartment completion inspections MHI

☐☐☒ HVAC pressure drop tests Hitachi

☐☐☒ HVAC pressure drop tests Odense

☐☐☒ HVAC pressure drop tests MHI

**Interim Products**

☐☐☒ Final in-shop testing and inspection of interim products (e.g., machinery testing, piping bundle hydro testing) Hitachi

☐☐☒ Final in-shop testing and inspection of interim products (e.g., machinery testing, piping bundle hydro testing) Odense

☐☐☒ Final in-shop testing and inspection of interim products (e.g., machinery testing, piping bundle hydro testing) MHI

**High-Level Resource Planning and Scheduling:** Includes overall build strategy development, major milestone level planning, block production and erection schedules, test and inspection schedules, trials and delivery, facilities planning and scheduling, engineering planning and scheduling, training and qualification issues.

**High-Level Resource Planning and Scheduling (cont.)**

**Structure and Outfitting**

☐☐☒ Build strategy development Odense

☒☐☐ Build strategy development Hitachi

☐☐☒ Build strategy development MHI

☐☒☐ Cost estimation and tracking (e.g., steel work) Odense

☒☐☐ Cost estimation and tracking (e.g., steel work) Hitachi

☐☒☐ Cost estimation and tracking (e.g., steel work) MHI

☐☒☐ Routing and route checking for parts and assemblies Odense

☒☐☐ Routing and route checking for parts and assemblies Hitachi

☐☐☒ Routing and route checking for parts and assemblies MHI

☐☒☐ Rule checking (e.g., crane capacity, size restriction) Odense

	<input checked="" type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>	Rule checking (e.g., crane capacity, size restriction) Hitachi
	<input type="checkbox"/> <input type="checkbox"/> <input checked="" type="checkbox"/>	Rule checking (e.g., crane capacity, size restriction) MHI
	<input checked="" type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>	Bills of materials development and updating Odense
	<input checked="" type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>	Bills of materials development and updating Hitachi
	<input checked="" type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>	Bills of materials development and updating MHI
	<input checked="" type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>	Material take-off Odense
	<input checked="" type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>	Material take-off Hitachi
	<input type="checkbox"/> <input type="checkbox"/> <input checked="" type="checkbox"/>	Material take-off MHI
	<input checked="" type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>	Production work management (e.g., by job, by drawing, by process) Odense
	<input checked="" type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>	Production work management (e.g., by job, by drawing, by process) Hitachi
	<input checked="" type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>	Production work management (e.g., by job, by drawing, by process) MHI
	<input checked="" type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>	Performance measurement Odense
	<input checked="" type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>	Performance measurement Hitachi
	<input type="checkbox"/> <input checked="" type="checkbox"/> <input type="checkbox"/>	Performance measurement MHI
	<input checked="" type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>	Production status tracking and feedback (e.g., labor and material costs for fabrication, steel assembly and installation) Odense
	<input checked="" type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>	Production status tracking and feedback (e.g., labor and material costs for fabrication, steel assembly and installation) Hitachi
	<input type="checkbox"/> <input type="checkbox"/> <input checked="" type="checkbox"/>	Production status tracking and feedback (e.g., labor and material costs for fabrication, steel assembly and installation) MHI
	<input checked="" type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>	Release of work to production Odense
	<input checked="" type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>	Release of work to production Hitachi
	<input type="checkbox"/> <input type="checkbox"/> <input checked="" type="checkbox"/>	Release of work to production MHI
	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>	Inventory cycle counts and accuracy rates Odense
	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>	Inventory cycle counts and accuracy rates Hitachi
	<input type="checkbox"/> <input type="checkbox"/> <input checked="" type="checkbox"/>	Inventory cycle counts and accuracy rates MHI
Odense	<input checked="" type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>	Planning and scheduling (e.g., labor requirements, capacity/resource planning, reports)
Hitachi	<input checked="" type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>	Planning and scheduling (e.g., labor requirements, capacity/resource planning, reports)
MHI	<input checked="" type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>	Planning and scheduling (e.g., labor requirements, capacity/resource planning, reports)
Interim Products		
	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>	Integration of build strategy Odense
	<input type="checkbox"/> <input checked="" type="checkbox"/> <input type="checkbox"/>	Integration of build strategy Hitachi
	<input type="checkbox"/> <input type="checkbox"/> <input checked="" type="checkbox"/>	Integration of build strategy MHI
	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>	Automation of build strategy Odense
	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>	Automation of build strategy Hitachi
	<input type="checkbox"/> <input type="checkbox"/> <input checked="" type="checkbox"/>	Automation of build strategy MHI

**Production Engineering:** The interface between design and production. Includes all detailed planning, definition of work packages, development of product work breakdown structure, interface between CAD and CAM, and design related production support.

#### Structure and Outfitting

- ☒☐☐ Development of production packages support steel fabrication and erection Odense
- ☒☐☐ Development of production packages support steel fabrication and erection Hitachi
- ☐☐☒ Development of production packages support steel fabrication and erection MHI

- ☒☐☐ Development of unit handling (lifting, bracing) sketches or documents Hitachi
- ☐☒☐ Development of unit handling (lifting, bracing) sketches or documents Odense
- ☐☐☒ Development of unit handling (lifting, bracing) sketches or documents MHI

- ☒☐☐ Nesting of parts for structural plate, shapes and sheet metal Hitachi
- ☒☐☐ Nesting of parts for structural plate, shapes and sheet metal Odense
- ☒☐☐ Nesting of parts for structural plate, shapes and sheet metal MHI

- ☒☐☐ Documentation of production processes Hitachi
- ☒☐☐ Documentation of production processes Odense
- ☐☐☒ Documentation of production processes MHI

- ☒☐☐ Simulation of production processes Hitachi
- ☒☐☐ Simulation of production processes Odense
- ☐☐☒ Simulation of production processes MHI

- ☒☐☐ Development and issue of work order or shop information Odense
- ☒☐☐ Development and issue of work order or shop information Hitachi
- ☐☐☒ Development and issue of work order or shop information MHI

#### Interim Products Hitachi

- ☐☒☐ Use of standards Odense
- ☐☒☐ Use of standards Hitachi
- ☐☐☐ Use of standards MHI

- ☐☒☐ Development of interim product processes Odense
- ☐☒☐ Development of interim product processes Hitachi
- ☐☐☒ Development of interim product processes MHI

**Purchasing/Procurement:** Covers all areas of material ordering, procurement and supplier relations. Includes interfaces with bill of materials systems and cost estimating, long lead time material ordering, obtaining and processing vendor furnished information, and processing and tracking of purchase orders.

#### Structure and Outfitting

- ☒☐☐ Material management to ensure on-time availability in support of production. Odense
- ☒☐☐ Material management to ensure on-time availability in support of production. Hitachi
- ☐☐☒ Material management to ensure on-time availability in support of production. MHI

- ☒☐☐ Yard stock material management (e.g., flat bar and temporary attachments - ordering, providing to production) Odense
- ☒☐☐ Yard stock material management (e.g., flat bar and temporary attachments - ordering, providing to production) Hitachi
- ☐☐☒ Yard stock material management (e.g., flat bar and temporary attachments - ordering, providing to production) MHI

- ☒☐☐ Long lead time material procurement Odense
- ☒☐☐ Long lead time material procurement Hitachi

☐☐☒ Long lead time material procurement MHI

☒☐☐ Direct material stocking to production by vendors Odense

☒☐☐ Direct material stocking to production by vendors Hitachi

☐☐☒ Direct material stocking to production by vendors MHI

☐☐☒ Purchase of pre-construction primed structural materials Odense

☒☐☐ Purchase of pre-construction primed structural materials Hitachi

☐☐☐ Purchase of pre-construction primed structural materials MHI

☐☒☐ Interfaces with bill of materials systems Odense

☒☐☐ Interfaces with bill of materials systems Hitachi

☒☐☐ Interfaces with bill of materials systems MHI

☐☒☐ Obtaining and processing vendor furnished information Odense

☒☐☐ Obtaining and processing vendor furnished information Hitachi

☐☐☒ Obtaining and processing vendor furnished information MHI

☒☐☐ Processing and tracking of purchase orders Odense

☒☐☐ Processing and tracking of purchase orders Hitachi

☐☐☒ Processing and tracking of purchase orders MHI

☐☐☐ Support of tendering Odense

☒☐☐ Support of tendering Hitachi

☐☐☒ Support of tendering MHI

#### Interim Products

☐☐☒ Allocation of indirect costs to interim products Odense

☐☐☐ Allocation of indirect costs to interim products Hitachi

☐☐☐ Allocation of indirect costs to interim products MHI

**Shop Floor Resource Planning and Scheduling:** Covers planning and scheduling issues not included in high level planning and scheduling. Issues include shop floor and process lane layouts, equipment and personnel scheduling, detailed planning, work order development, labor and/or cost control, job statusing, machine sequencing and shop capacity planning.

#### Structure and Outfitting

☒☐☐ Provision of information to the shop (e.g., drawings, schematics, lofting information, work instructions, ship location reference marks, welding reference lines, machine setup instructions) Odense

☒☐☐ Provision of information to the shop (e.g., drawings, schematics, lofting information, work instructions, ship location reference marks, welding reference lines, machine setup instructions) Hitachi

☐☒☐ Provision of information to the shop (e.g., drawings, schematics, lofting information, work instructions, ship location reference marks, welding reference lines, machine setup instructions) MHI

☒☐☐ Work order/work station tracking and control at the supervisor level Odense

☒☐☐ Work order/work station tracking and control at the supervisor level Hitachi

☒☐☐ Work order/work station tracking and control at the supervisor level MHI

☒☐☐ Workstation synchronization Odense

☒☐☐ Workstation synchronization Hitachi  
☒☐☐ Workstation synchronization MHI

☒☐☐ Systems for Detailed Planning Odense  
☒☐☐ Systems for Detailed Planning Hitachi  
☒☐☐ Systems for Detailed Planning MHI

☒☐☐ Release work to production Odense  
☒☐☐ Release work to production Hitachi  
☐☐☒ Release work to production MHI

☒☐☐ Detailed capacity planning for a shop or area Odense  
☒☐☐ Detailed capacity planning for a shop or area Hitachi  
☒☐☐ Detailed capacity planning for a shop or area MHI

#### Interim Products

☒☐☐ Collect and calculate total labor and material direct costs for a major assembly Odense  
☒☐☐ Collect and calculate total labor and material direct costs for a major assembly Hitachi  
☒☐☐ Collect and calculate total labor and material direct costs for a major assembly MHI

☐☐☒ Trade coordination on multi-trade assemblies Odense  
☒☐☐ Trade coordination on multi-trade assemblies Hitachi  
☐☐☒ Trade coordination on multi-trade assemblies MHI

☐☒☐ Shift turnover information and briefings Odense  
☒☐☐ Shift turnover information and briefings Hitachi  
☐☐☒ Shift turnover information and briefings MHI

**Quality Control and Assurance, SOC:** Includes all aspects of quality control and assurance starting in design, through production, including development of dimensional tolerance information and reference line systems, distortion control, dimensional data gathering in production, statistical process control and statistical quality control.

#### Structure and Outfitting

☐☐☒ Use of accuracy control standards Odense  
☐☒☐ Use of accuracy control standards Hitachi  
☐☐☒ Use of accuracy control standards MHI

☒☐☐ Verification of NC data with respect to design base Odense  
☒☐☐ Verification of NC data with respect to design base Hitachi  
☐☐☒ Verification of NC data with respect to design base MHI

☐☐☒ Quality trend analyses (e.g., SPS) Odense  
☐☒☐ Quality trend analyses (e.g., SPS) Hitachi  
☐☐☒ Quality trend analyses (e.g., SPS) MHI

☐☒☐ Distortion control (e.g., temporary restraining structures, weld shrinkage affects) Odense  
☐☒☐ Distortion control (e.g., temporary restraining structures, weld shrinkage affects) Hitachi  
☐☐☒ Distortion control (e.g., temporary restraining structures, weld shrinkage affects) MHI

☐☒☐ Dimensional accuracy methods (e.g., plate level rolling, straightening, mill tolerance allowances, trim cutting) Odense

- ☐ ☒ ☐ Dimensional accuracy methods (e.g., plate level rolling, straightening, mill tolerance allowances, trim cutting) Hitachi
- ☐ ☐ ☒ Dimensional accuracy methods (e.g., plate level rolling, straightening, mill tolerance allowances, trim cutting) MHI
- ☐ ☒ ☐ Part size tolerance determination (e.g., through standards or determined individually during detail design) Odense
- ☐ ☒ ☐ Part size tolerance determination (e.g., through standards or determined individually during detail design) Hitachi
- ☐ ☐ ☒ Part size tolerance determination (e.g., through standards or determined individually during detail design) MHI
- ☒ ☐ ☐ Dimensional tolerance information Odense
- ☒ ☐ ☐ Dimensional tolerance information Hitachi
- ☐ ☐ ☒ Dimensional tolerance information MHI
- ☐ ☒ ☐ Dimensional data gathering (e.g., optical, laser, photogrammetry) Odense
- ☐ ☒ ☐ Dimensional data gathering (e.g., optical, laser, photogrammetry) Hitachi
- ☐ ☐ ☒ Dimensional data gathering (e.g., optical, laser, photogrammetry) MHI

#### Interim Products

- ☐ ☒ ☐ Dimensional data gathering (e.g., optical, laser, photogrammetry) Odense
- ☐ ☒ ☐ Dimensional data gathering (e.g., optical, laser, photogrammetry) Hitachi
- ☐ ☐ ☒ Dimensional data gathering (e.g., optical, laser, photogrammetry) MHI
- ☐ ☒ ☐ Adjustments to design part dimensions based on as-built assembly dimensional measurements Odense
- ☐ ☒ ☐ Adjustments to design part dimensions based on as-built assembly dimensional measurements Hitachi
- ☐ ☐ ☒ Adjustments to design part dimensions based on as-built assembly dimensional measurements MHI
- ☐ ☐ ☐ Tolerancing Odense
- ☐ ☒ ☐ Tolerancing Hitachi
- ☐ ☐ ☒ Tolerancing MHI
- ☐ ☐ ☐ Dimensional error calculations Odense
- ☐ ☐ ☐ Dimensional error calculations Hitachi
- ☐ ☐ ☒ Dimensional error calculations MHI

#### General

- ☒ ☐ ☐ Design methods (e.g., manual, CAD, CAM, CIM, product model) Odense
- ☒ ☐ ☐ Design methods (e.g., manual, CAD, CAM, CIM, product model) Hitachi
- ☒ ☐ ☐ Design methods (e.g., manual, CAD, CAM, CIM, product model) MHI
- ☒ ☐ ☐ Development and updating of bills of material Odense
- ☒ ☐ ☐ Development and updating of bills of material Hitachi
- ☒ ☐ ☐ Development and updating of bills of material MHI
- ☒ ☐ ☐ Production and support organization use of cost information Odense
- ☒ ☐ ☐ Production and support organization use of cost information Hitachi

- ☐ ☒ ☐ Production and support organization use of cost information MHI
- ☐ ☒ ☐ Development and use of product and process standards (e.g., structure scantling design, structural parts) Odense
- ☒ ☐ ☐ Development and use of product and process standards (e.g., structure scantling design, structural parts) Hitachi
- ☐ ☐ ☒ Development and use of product and process standards (e.g., structure scantling design, structural parts) MHI
- ☐ ☐ ☐ Design/product definition (e.g., steel fabrication and erection, standard interim products, knowledge-based systems) Odense
- ☒ ☐ ☐ Design/product definition (e.g., steel fabrication and erection, standard interim products, knowledge-based systems) Hitachi
- ☐ ☒ ☐ Design/product definition (e.g., steel fabrication and erection, standard interim products, knowledge-based systems) MHI
- ☒ ☐ ☐ Weights and centers determination Odense
- ☒ ☐ ☐ Weights and centers determination Hitachi
- ☐ ☒ ☐ Weights and centers determination MHI
- ☐ ☒ ☐ Responses to shop floor disruption (e.g., machine breakdown, design data error) Odense
- ☐ ☒ ☐ Responses to shop floor disruption (e.g., machine breakdown, design data error) Hitachi
- ☐ ☐ ☒ Responses to shop floor disruption (e.g., machine breakdown, design data error) MHI
- ☐ ☐ ☐ Accuracy measurement and control (e.g., for CAD/CAM data, BOM, inventory, material lead time) Odense
- ☐ ☒ ☐ Accuracy measurement and control (e.g., for CAD/CAM data, BOM, inventory, material lead time) Hitachi
- ☐ ☐ ☒ Accuracy measurement and control (e.g., for CAD/CAM data, BOM, inventory, material lead time) MHI
- ☐ ☒ ☐ High level processes for design, planning, scheduling, material handling, regulatory approval, owner approval, and production Odense
- ☒ ☐ ☐ High level processes for design, planning, scheduling, material handling, regulatory approval, owner approval, and production Hitachi
- ☐ ☒ ☐ High level processes for design, planning, scheduling, material handling, regulatory approval, owner approval, and production MHI
- ☐ ☐ ☒ Consideration of customer requirements Odense
- ☐ ☐ ☒ Consideration of customer requirements Hitachi
- ☐ ☐ ☒ Consideration of customer requirements MHI
- ☒ ☐ ☐ Part numbers development and use Odense
- ☒ ☐ ☐ Part numbers development and use Hitachi
- ☐ ☐ ☐ Part numbers development and use MHI
- ☐ ☐ ☒ Error detection and handling Odense
- ☐ ☒ ☐ Error detection and handling Hitachi
- ☐ ☐ ☒ Error detection and handling MHI
- ☐ ☐ ☒ Shipyard-vendor relationships Odense
- ☐ ☒ ☐ Shipyard-vendor relationships Hitachi
- ☐ ☐ ☒ Shipyard-vendor relationships MHI
- ☒ ☐ ☐ Configuration management Odense

☐☒☐ Configuration management Hitachi  
☐☐☒ Configuration management MHI

☒☐☐ Design revision process after initial design release Odense  
☒☐☐ Design revision process after initial design release Hitachi  
☐☐☒ Design revision process after initial design release MHI

☒☐☐ Use of robotics Odense  
☒☐☐ Use of robotics Hitachi  
☒☐☐ Use of robotics MHI

☐☐☐ Continuous improvement process Odense  
☐☐☒ Continuous improvement process Hitachi  
☐☐☐ Continuous improvement process MHI

☐☒☐ High level sequence of events of a ship design and production cycle Odense  
☒☐☐ High level sequence of events of a ship design and production cycle Hitachi  
☒☐☐ High level sequence of events of a ship design and production cycle MHI

☒☐☐ Methods for data backup and recovery Odense  
☐☒☐ Methods for data backup and recovery Hitachi  
☐☐☒ Methods for data backup and recovery MHI

☒☐☐ Production automation Odense  
☐☒☐ Production automation Hitachi  
☒☐☐ Production automation MHI

☐☐☐ Development and updating of work breakdown organization/structure Odense  
☐☒☐ Development and updating of work breakdown organization/structure Hitachi  
☐☐☒ Development and updating of work breakdown organization/structure MHI

☐☒☐ Methods for shop floor feedback to engineering/production Odense  
☐☐☒ Methods for shop floor feedback to engineering/production Hitachi  
☐☒☐ Methods for shop floor feedback to engineering/production MHI

☐☐☒ Process and tools documentation (e.g., procedures manuals, imbedded in software)

Hitachi

☐☒☐ Process and tools documentation (e.g., procedures manuals, imbedded in software)

Odense

☐☐☒ Process and tools documentation (e.g., procedures manuals, imbedded in software) MHI

## Odense Survey Results

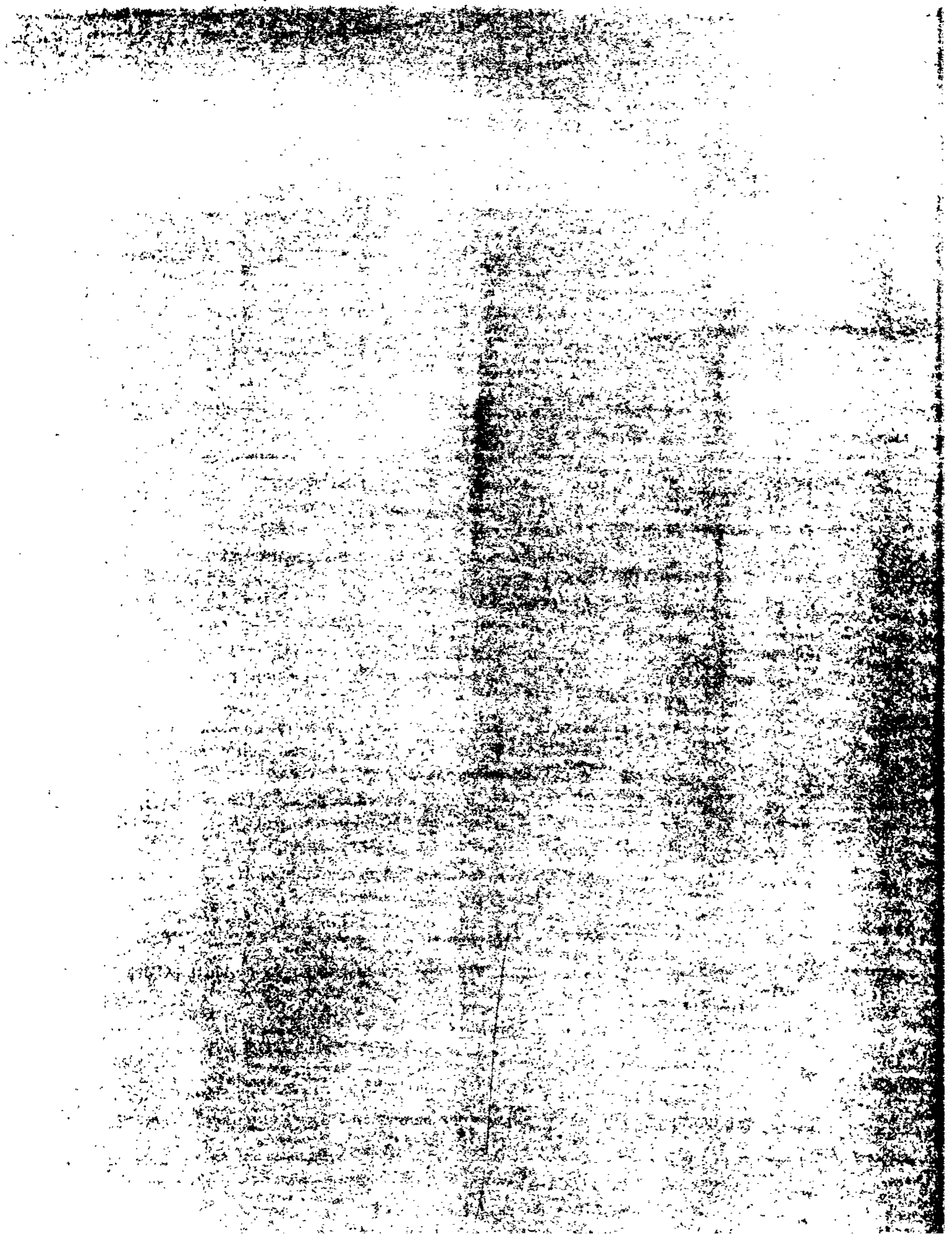
	Design			Production					Operations Management				
	Conceptual/Preliminary	Functional	Detailed	Fabrication Processes	Joining and Assembly Processes	Surface Treatment & Coating	Material Control	Testing/Inspection	High-Level Resource Planning and Scheduling	Production Engineering	Purchasing/Procurement	Shop Floor Resource Planning and Scheduling	Quality Control & Assurance, SQC
Hull Structure	□ □ □ □	□ □ □ □	□ □ □ □ □ □ □ □ □ □	□ □ □ □ □ □ □ □ □ □	□ □ □ □ □ □ □ □ □ □	□ □ □ □ □ □ □ □ □ □	□ □ □ □ □ □ □ □ □ □	□ □ □ □ □ □ □ □ □ □	□ □ □ □	□ □ □ □ □ □ □ □ □ □	□ □ □ □	□ □ □ □ □ □ □ □ □ □	□ □ □ □ □ □ □ □ □ □
Outfitting	□ □ □ □	□ □ □ □	□ □ □ □ □ □ □ □ □ □	□ □ □ □ □ □ □ □ □ □	□ □ □ □ □ □ □ □ □ □	□ □ □ □ □ □ □ □ □ □	□ □ □ □ □ □ □ □ □ □	□ □ □ □ □ □ □ □ □ □	□ □ □ □	□ □ □ □ □ □ □ □ □ □	□ □ □ □	□ □ □ □ □ □ □ □ □ □	□ □ □ □ □ □ □ □ □ □
Interim Products		□ □ □ □ □ □ □ □ □ □	□ □ □ □ □ □ □ □ □ □	□ □ □ □ □ □ □ □ □ □	□ □ □ □ □ □ □ □ □ □	□ □ □ □ □ □ □ □ □ □	□ □ □ □ □ □ □ □ □ □	□ □ □ □ □ □ □ □ □ □		□ □ □ □	□ □ □ □ □ □ □ □ □ □	□ □ □ □ □ □ □ □ □ □	□ □ □ □ □ □ □ □ □ □

# MHI Survey Results

Design				
Functional	7000	7000	7000	
Detailed	10000000	10000000	10000000	
Fabrication Processes	10000000	10000000	10000000	
Joining and Assembly Processes	7000	7000	7000	
Surface Treatment & Coating	10000000	10000000	10000000	
Material Control	10000000	10000000	10000000	
Testing/Inspection	10000000	10000000	10000000	
High-Level Resource Planning and Scheduling	7000	7000	7000	
Production Engineering	7000	7000	7000	
Purchasing/Procurement	10000000	10000000	10000000	
Shop Floor Resource Planning and Scheduling	7000	7000	7000	
Quality Control & Assurance, SQC	10000000	10000000	10000000	
Production				
Operations Management				

## Hitachi Zosen Survey Results

[illegible]



## **Appendix G**

### **EVALUATION PROJECT PARTICIPANTS**

The project team assembled to evaluate world-class shipbuilding CAD/CAM/CIM systems included the following members:

John Horvath, NASSCO (Project Manager)  
Richard Moore, UMTRI (Principal Investigator)  
Thomas Brown, McDermott  
Richard Buckheister, Avondale  
Joseph Carlantonio, McDermott  
Gouglas Geheb, Bath Iron Works  
Michael Gerardi, Bath Iron Works  
Dale Jermyn, Avondale  
Kenton Meland, Newport News Shipbuilding  
Ken Pleasant, Newport News Shipbuilding  
Ron Reeve, Cybo Robots  
Jonathan Ross, Proteus Engineering  
Steve Stroebel, NASSCO  
Dan Wooley, Newport News Shipbuilding

The project team would like to acknowledge the individual contributions by the following people in the organizations which participated in this evaluation study. Their preparation and openness during the evaluation discussions and demonstrations were instrumental to the success of the evaluations.

#### **Black & Veatch**

Darci Jo O'Brien P.E.  
John G. Voeller, Senior Partner

#### **Caretronic**

Reinhard Oelze, Dipl.-Ing.  
Walter H. Thomsen, Dipl.-Ing.

#### **Computervision Corporation**

Michael P. Kernler, Principal Consultant  
Stafano Malnati  
Roland Scott, Marketing Executive

**Hitachi Zosen Corporation**

Kenji Doi, Manager  
Koji Hayakaws, Associate Director  
Takanori Itoh, General Manager  
Fusaichi Katayama, Division Manager  
Tatsuo Miyazaki, General Manager, Production Technology Development Department  
Kousuke Mukasa, General Manager, Design Department  
Hirotaka Shirakami, Associate Director

**IHI Marine International, Inc.**

Tadaaki Tsuna, Senior Manager

**Industrial Technology Institute**

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Steve A. Harris, Associate Director  
H. Van Dyke Parunak Ph.D., Scientific Fellow  
John A. Sauter, Associate Director  
Ray VanderBok, Technical Staff

**Intergraph Corporation**

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Doug Hilton  
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John Riddle  
Glenn Williams

**Ishikawajima-Harima Heavy Industries Co., Ltd.**

Norio Hata Project Leader  
Kohji Honda, Manager  
Masataka Kakimoto, Manager  
Hiroshi Katayama, General Manager  
Hideaki Kikumoto, Section Manager  
Shin Noda, Manager  
Toshiyuki Takata  
Naoteru Tsuda, General Superintendent

**Kockums Computer Systems AB**

Bruce Douglas, Executive Vice President  
Kaj Johansson, Executive Vice President  
Goran Martensson, Senior Manger  
Roy Metcalfe, Senior Manager  
Bryan J. Miller, President  
LeifPergler, Executive Vice President

**Logimatic**

Lars R. Borghun, Project Manager

**Mitsubishi Heavy Industries, Ltd.**

Shuichi Fukahori, Project Manager

Akio Iida, Project Manager

Ken Ito, Senior Project Manager

Hiroaki Mihara Acting Manager

Takashi Oshiba, Project Manager

Yuichi Sasaki, Research Engineer

Masahiro Sonda, Acting Manager

Tetsuo Yasumoto, Group Manager

Takashi Yoshimura, Project Manager

**Norddeutsche Informations-Systeme GmbH**

Frank Hollenberg, Dr.-Ing.

Holger Pape, Diplom-Physiker

Thomas Schultz, Diplom-Ingenieur

Dr. Lutz Vietze, Dr.-Ing.

Dr. Doris Wessels, Diplom-Mathematikerin

**Odense Steel Shipyard Ltd.**

Torben Anderson, Executive Vice-President

Hans Jorgen Christensen, Naval Architect

Torsten Clasuen, Coordinator, Planning & Control

Allan Dinesen, Engineer, System Manager

Robin Fonseca, Steel Production

Erik K. Hansen, Coordinator, CAD/CAM

Arne R. Henriksen, Coordinator, CAD/CAM

Ole K. Knudsen, Coordinator, Pipe Shop

Keld Heddal Nielsen, General Manager

Vesti G. Nielsen, Coordinator, Steel Production

Ejgil Norgaard, Naval Architect

Jens Jorgen Rasmussen, Coordinator, Bills of Material

Torben W. Rasmussen, Coordinator, Material Planning & Control

Carl Erik Skjølstrup, Manager Automation Development

Hans E. Sornrner, Manager Production Engineering

Jorgen Chri. Sorensen, Coordinator, VLCC visit

Bjorn Trasbo, Naval Architect

**Sener Ingerieria Y Sistemas, S.A.**

Fernando Alonso, Manager

Juan L. Caverio

Luis Garcia, International Sales Manager  
Dr. Ing. Jaime Torroja, General Manager

**S.M.K. Ingenieurburo**

Dipl. Ing. Hans Matthiesen  
Dipl. Ing. Axel Schroeter

**Verolme**

C. L. de Zwart  
Th.A.F. Pelders

Ž use the best practices available related to people, processes, facilities and technology.

This report concentrates on the specifics of technology but it is not possible to decouple technology from the other factors listed above. Specifically, we have observed that certain technologies - in particular CAD/CAM/CIM and accuracy control - are essential enabling ingredients in 1996 “world class” commercial shipbuilding. However, effective CAD/CAM/CIM and accuracy (i.e. elimination of variations) technologies are not the only deciding factors.

The assessed shipyards represent the survivors of significant industry reductions in both Japan and Europe. These shipyards have adopted strategies which produced improved business results primarily through continually reducing materials costs and labor content. Lower cost alternatives have also been developed, such as reliance on managed networks of suppliers and subcontractors for many components and services. Actual on-site shipyard work concentrates on only those tasks which the yard does best: their “core competencies”. For example, in all shipyards, structural fabrication was a core competency.

A key factor in achieving essential business improvements appeared to be a clear identification and communication of the business goal and strategy to the work force. This process is top-down driven with executive management actively supporting the initiatives with intensity over the full duration required for implementation. Just as importantly, the work force is directly involved in understanding the barriers and designing and implementing the process changes from the bottom-up. The processes were observed to be handled indifferent ways in the different cultures. At Hitachi, each employee provides 1 or 2 suggestions per month which are all reviewed by management and over 50% are implemented. At Odense, all executives, production management and union workers are involved with the approval of estimates and schedules for a new ship contract. During project execution all are accountable for achieving the required contract performance.

The yards studied are in the range of 20-30 labor hours per CGT with Odense quoting 10 labor hours per ton of steel for structural work. Due to different strategies and core competencies, these figures are difficult to correlate with the specific work force information provided. However, the small number of total workers is consistent with the quoted productivity.

The following report is assembled as a descriptive overview of the information gleaned by the project team. Detail is omitted by necessity rather than choice. However, the detail has been considered by the team during Phase 2 of the project in developing the requirements for a world-class, future-oriented U.S. shipbuilding CAD/CAM/CIM system. Access to detailed information collected during the assessment visits is available through the individual team members.

## **12.0 INTERGRAPH**

Founded in 1969 as M&S Computing, Intergraph is now a \$1B/year Fortune 1000 Company serving a wide range of computing systems needs for commercial and government organizations.

Intergraph is the prime contractor for the Navy's CAD-2 shipbuilding software and provides an Integrated Ship Design and Production (ISDP) system for commercial shipbuilding applications.

### **12.1 ISDP OVERVIEW**

Integrated Ship Design and Production, or ISDP, refers to a suite of software applications that address a number of ship design areas. Based on Intergraph's Vehicle Design System (VDS) core software, which is itself based on Intergraph's Engineering Modeling System (EMS), the ISDP applications enable 3-D solids model based modeling of complete ship structures and systems. The individual components of ISDP and their function within the suite are as follows:

**Vehicle Design System (VDS)** - The basic modeling package. All machinery and component modeling is done within VDS. Compartmentation is also defined within VDS. Parts created in VDS contain graphical data, may or may not be associative, and carry extensive, user definable attribute data in a separate file. The basic functions within VDS are icon driven, however, there are numerous design activities that require data input from the user via on-line forms.

**ISTRUCT** - The structural modeling package. ISTRUCT allows the designer to model all of the ship's structure using an extensive user definable library of structural components. Structural modeling can be accomplished with M1 associativity, so that changes in a portion of the model will automatically update all associated parts.

**IROUTE** - Accomplishes all of the distributed systems design, including piping, HVAC and electrical cableways. IROUTE is also a fully associative modeler, allowing systems to automatically update when any associated component is moved.

**ILOFT** - Intergraph's nesting and lofting software, designed to work with ISTRUCT. Rimbaud is incorporated as the nesting software.

**Output Product Enhancement (OPE)** - This is a recently added package that enhances Intergraph's ability to produce shop quality printed drawings from the product

model. The package also enables bills of material and revision histories, both of which can be separately exported as ASCII files for use in spreadsheets or databases.

In addition to product modeling, ISDP enhances enterprise wide data management through the Product Data Manager (PDM) and Data Manager 2 (DM2). All of the product model data are stored in an SQL compliant database, and can be accessed, sorted, queried, and managed with PDM and DM2.

#### 12.1.1 Database

The ISDP database is highly dependent on user input during design. Because of the physical structure of the model, it is difficult to add additional attributes to a part once the part has been placed in the model. For this reason it is extremely important that the required data be identified at the start of the modeling effort and to ensure that all parts generated during modeling use the specified attribute tables.

#### 12.1.2 General/Conceptual Design

ISTRUCT has the ability to import hullform data directly from Fastship as fully associative NURBS surfaces. This makes it especially useful as a conceptual design tool if the user has a well established library of components that can be placed in the model to analyze space relationships, weights and centers, and other early design parameters. Changes to the hull form can be incorporated without making changes to the structure or equipment. ISDPS parametric design capability also allows changes to be incorporated by changing specific design parameters of individual components.

#### 12.1.3 Structural Design

As a structural design tool, ISTRUCT can be employed very effectively. Parametric design of structural elements enables the development of libraries of structural shapes, which are used parametrically by placing them in the model with appropriate changes to parameters such as length, flange thickness, and web size. Compound curvature of plate surfaces is possible, and plate and stiffeners can be associatively designed so that changes to one result in updates to the associated parts. By assigning material properties to the structural elements as attributes, detailed weight reporting is enabled very early in the design. Files generated by ISTRUCT can be used in ILOFT to generate shop level information and NC code. OPE enables the extraction of structural drawings, provided the model structure is properly designed.

#### 12.1.4 Outfitting Design

The IROUTE package enables the design of distributed system runs both as single line representations and as full three-dimensional models. Associativity can be established with equipment, structure and other outfitting systems. The equipment modeling function within VDS completes the outfit design capability of ISDP.

#### 12.1.5 Associativity and Interference Detection

VDS is a fully associative modeler that can be disabled or enabled by the operator. Associativity and parametric modeling allow a greater degree of flexibility in design decision making, and allow greater degrees of detail to be incorporated at earlier stages of design. Also, the use of “instances” of a part in the product model allows the operator to update a single master file for changes to a particular part and then automatically update all instances of that part in the model. This flexibility minimizes re-design work, and decreases the slope of the cost of change versus stage of design curve.

Interference checking is incorporated into VDS, and can be done with definable measures for collision. Proper modeling results in components with overall dimensions, operating, and maintenance envelopes defined. Interference checking can be done against any one of these envelopes, either system by system, or with all systems, structure, and components active. Hard and soft interferences are shown graphically at the operator’s workstation, and an interference report can be generated identifying all interferences found.

### 12.2 IMPLEMENTATION APPROACHES

ISDP has not been fully implemented by any U.S. shipyards. A Korean version of the package is currently being used in the Far East. The Navy’s CAD-2 program has implemented a number of functions of ISDP, but does not cover the full scope of design and production of which ISDP is capable.

One of the major impediments in the implementation of ISDP (or most any comprehensive design and production system) is the difficulty of incorporating legacy data into the enterprise database. Associative models must be designed from the start using VDS, effectively eliminating any possibility of using legacy graphical data. Attribute data can be bulk loaded into the system, but the new database must have the same basic structure as the legacy data in order to do so. The “out of the box” libraries within VDS meet only the most basic needs, and require extensive updating to incorporate shipyard specific practices and materials. Abroad spectrum of structural and outfitting library parts, such as end treatments, nonstandard shapes, and yard specific fittings were not anticipated by Intergraph in the stock release of ISDP.

Effective implementation of ISDP requires a carefully planned and deliberate transition, as well as a commitment to invest capital in the development of the required libraries and databases. Cross functionality of the design team is necessary to ensure that product model data are incorporated with the right level of detail at the right stage of design.

### 12.3 PRODUCT MODELING TECHNOLOGY

ISDP is an evolutionary software, relying on technology that has existed for several years in EMS and VDS. Developments in object oriented software have been incorporated, making ISDP competitive with the other major shipbuilding software in terms of capability. However, a revolutionary approach, which Intergraph is undertaking with their Jupiter software, may make ISDP a true standout in terms of product modeling technology.

### 12.4 INTEGRATION

ISDP is not currently well integrated with other third party software. It can import Fastship hullforms, and can translate dxf and IGES files. However, there is no capability to import or export associativity or parametric intelligence. In addition, the file structure relationship between the attribute data and the graphical data is lost in the translation process. However, new developments in software standards, particularly with OLE, suggest a greater degree of compatibility between unrelated software. In addition, Intergraph's commitment to make Windows NT the operating system of choice may resolve many of the operating system incompatibility issues.

### 12.5 ISDP FUTURES

The emphasis of Intergraph's development efforts appear to be broad in scope, addressing the enterprise-wide automation and communication needs rather than just the CAD/CAM issues. The Windows NT operating system and multiprocessor PCs are viewed as the high productivity environment and cost/performance hardware platforms of the future. The common look and feel between shipbuilding CAD/CAM systems and widely used word processing and spreadsheet type applications is expected to minimize the learning curve costs. Similarly, standards, such as open GL, will enhance effective integration with other applications.

Object linking and embedding (OLE) capabilities to link CAD applications with other business process applications are believed to be important to ISDP users. Document management integrated with data management will be required. Driven in part

by Navy CAD-2 considerations, the notion of CAD system independent product models, including graphics and extensive attribute information may be an enabling technology.

Conceptual and preliminary design tools will need to move outside of the graphical modeling context in order to become more effective. Systems with component representations based on attributes (weight, space, etc.) and contextual relationships with other components will be needed to effectively address trade-offs between design concepts. This will likely involve compartmentalization of functional units. Once completed the conceptual representations based on attribute descriptions will then be further developed in a graphical context to produce CAD representations and eventually complete product models.

### 13.0 HICADEC

The HICADEC system was not evaluated as part of the MARITECH “Dry Cargo” project nor the benchmark study. Consequently, this trip report will include considerable background on this CAD/CAM system, which is extensively used at Odense (see Odense Visit description).

The first generation of the product, called “HIZAC” was developed by Hitachi Zosen and put into use in the 1960s. Development work continued in the 1970s to better integrate the various capabilities. The result was HICAS, a second generation product.

Beginning in 1981, Hitachi Zosen began work on the current product, a 3-D product model-based system integrating design, hull, arrangement, piping, electric, and production control. Wire-frame modeling methods are utilized for hull structure and distributed systems, such as piping. Solids modeling methods are only used for equipment and similar components, which don’t lend themselves to line or surface modeling techniques. The resulting HICADEC product was put into use in 1985/1986. The primary product emphasis is in the areas of detailed design and CAM (lofting, nesting, NC cutting and bending, and robotics). Interfaces with NAPA packages and BMT Hullsurf are touted as the means for accomplishing conceptual and preliminary design.

Currently, HICADEC is available on both SUN and Data General UNIX workstations running in X-Windows with clientserver capabilities.

The HICADEC system consists of four functionally independent subsystems covering the various functional design areas. These modules are as follows:

- HICADEC-H** Hull structure including parts naming, assembly networks, cutting and weld lengths, nesting, and NC data generation
- HICADEC-A** Arrangement design
- HICADEC-P** Piping, including diagrams, layout, specification, and piece marks
- HICADEC-E** Electrical, including diagrams, outfitting, cable management

A key feature of the HICADEC system is a part naming scheme consistent with the work breakdown structure. As 3-D product model data are developed, it is identified as belonging to a certain block and subassemblies comprising the block. Automatic naming can be utilized, based on the block and assembly hierarchy input for portions of the product model. The full hierarchy

describing the assembly sequence is maintained in an assembly network diagram. The hierarchy feature, along with attributes files, provides for generating lists and/or graphical information pertaining to selected portions of the product model. Likewise, this feature enables nesting to be done preliminarily for purchasing information and subsequently by block to support production schedules.

The piping subsystem provides a range of design checking to ensure that proper material specifications, pressure ratings, nominal sizes, etc. are consistent in each piping system. Interference checking capabilities are provided (between systems only, not including hull structure) and composite layouts can be displayed with color coding to visualize arrangements in congested areas. Similar to hull structure, the ship systems piping and equipment is segregated by block to facilitate preparation of lists and reports by block.

## **14.0 BLACK & VEATCH**

As part of the National Shipbuilding Research Program (NW?) project to evaluate shipbuilding CAD/CAM/CIM technology, the project team visited Black & Veatch on March 4, 1996. In the power and process industries, B&V are perceived to have very highly developed computer-aided management systems supporting their world-wide design and construction projects. Some of the concepts implemented in their systems were believed to be of significant interest for Navy procurements. We met with John Voeller, Senior Partner who led the POWRTRAK automation development effort. John provided an overview of Black & Veatch, then made the presentation of POWRTRAK, which has been previously presented to the U.S. Navy. In the afternoon, Darci O'Brien coordinated several short demonstrations of POWRTRAK capabilities.

It is believed that the POWRTRAK technology presentations have influenced some of the Navy's LPD-17 procurement requirements. Mr. Voeller described what he understands from the Navy (Robinson at NAVSEA) as general dissatisfaction about the information (primarily as-built data) delivered by shipbuilding contractors. It appears to be inaccurate (Captains can autonomously make changes) and insufficient for the Navy's life-cycle needs. Elements of the B&V POWRTRAK technology could be effective in improving shipbuilding information management in line with the Navy's needs.

### **14.1 POWRTRAK OVERVIEW**

Several key concepts were described as critical to the effectiveness of POWRTRAK in Black & Veatch's engineering, procurement and construction (EPC) businesses. These and other features of the system are briefly described as follows:

- . **Datacentric Orientation** Unlike traditional CAD systems, the orientation is on the individual part/components in a project and their attributes rather than the graphic representations of their geometry. Voeller described most CAD (graphics) approaches as frivolous, requiring CAD operators to do functions that should be computer-automated. AutoCAD tools are used to interface the core data in POWRTRAK for display purposes. In the datacentric view, each part/component exists in the project database in only one place. Different representations of these data are used for PID diagrams or 3-D modeling purposes.

Ž Project vs. Product Orientation Black& Veatch was described as a project-oriented organization rather than a product-producing organization. Consequently, the POWRTRAK system was built from a project management perspective rather than the product design perspective inherent with many CAD-based systems. Mr. Voeller indicated that the lack of attention to project management functions in the CAD Centre PDMS system is the fatal flaw in this software product.

. Database Technology The software was originally developed using Briton & Lee's hybrid relational and object-oriented database technology acquired by AT&T and implemented on AT&T workstations. Due to the AT&T acquisition of NCR and subsequent scrapping of the Briton & Lee technology, B&V sought anew database platform. They are currently moving towards Oracle because of the de-facto standard its SQL-compliant database provides in B&V's worldwide markets. The transition to Oracle on SUN workstations is scheduled for completion by year's end.

l Centralized Database A project's centralized database is accessible world-wide through T-1 phone lines and VSAT satellite communications. Pentium PCs seem to be the access platform of choice, although Evans and Sutherland workstations have historically provided most of the display capabilities.

. Parametric Libraries Extensive use of parametric definitions have been employed in building the CAD libraries of parts. For example, the entire AISC catalogue of steel WF shapes is defined by one library entry.

. Open access to information No attempt was made to presuppose employee access needs for project information. It is completely accessible (read only) to everyone in the project organization. Change control privileges are assigned to the project discipline, which is most affected by the data they control.

. Data States Each part/component has a data state associated with it over the duration of the project. During design, the data state moves from conceived, to decided (by designer), to broadcast (for review), to approved (by organization). Once approved, the data state can be on hold, or it can progress to planned (purchase and installation), to implemented (installed), to tested, to as-built.

. Trigger Functions Database segments are created by these functions to initiate subsequent engineering processes (by others). These functions

minimize the “invisible time” described by Voeller as the time project members wait for news that a change decision has been finalized. According to Voeller, this “invisible time” accounts for 25 percent of project costs in traditional engineering environments.

- Computer-Automated Engineering The traditional meaning of CAE (Computer-Assisted Engineering) was discarded in favor of emphasizing that systems should automate tasks with minimal user intervention (i.e. touch labor).
- Unique and Smart Part Numbering Each part has a unique ID number, even if the part is one of many standard parts (e.g. standard AISC W12X65 column section). The numbering scheme identifies the project number, system (e.g. fire water), component (e.g. pump), and unique ID number. This capability appears to facilitate progress tracking and rescheduling around strikes, shortages, accidents, and other schedule threatening events.

Visualization Graphics The graphics could best be described as spartan. They are not used to support marketing efforts, but only to ensure that layouts are functional, complete, and do not contain interferences or other design errors. Graphics are also used to display construction progress status. Minimal polygons are used to display data in order to emphasize speed over graphics quality.

The initial development efforts were started in 1979 and abandoned in 1985. After a \$ 10.9M investment in which the programmers dictated software developments, these automation developments were declared a bust because the users (engineers) wouldn't use the resulting software. From 1985 through 1994, B&V invested \$45M in developing information technologies using the lessons learned from the earlier efforts. Voeller stressed that the process must be right and well understood before automation can provide benefits.

The original development team numbered 28 people. Currently, B&V employs 140 for both software maintenance/enhancements, and consulting and external product marketing and support.

During the software demonstrations, it became apparent that some POWRTRAK functionality was not yet fully developed to the extent that the NSRP team has observed in some of the shipbuilding systems. For example, changes to the PID are not yet updated in the product model database. Workshop data interfaces, essential for lofting and nesting of plates in shipbuilding were not evident. Intefierence checking provided for both hard (share same space) and soft

('just touch) incidents, but could only be checked in batch mode generating incident lists. Resolved interferences accepted during one check could be marked so as to not reappear in future incident lists. Some level of system compatibility checking was evident such that a designer could not unknowingly place a six inch valve in an eight inch line. Similarly, components included in the PID, but not included in the 3-D product model, would be detected and reported by the system.

#### 14.2 BLACK & VEATCH USAGE/BENEFITS

The primary benefits of the POWRTRAK system were described as (1) risk management, and (2) schedule and cost reduction. Mr. Voeller suggested that B&V finds a 50-100 MW plant to be about the minimum size project for effective use. Typical projects at B&V are in the 500-600 MW range, with installed costs driven from \$1000/KW seven years ago to about \$450/KW, partly through the use of POWRTRAK.

Since the introduction of POWRTRAK in 1988, B&V revenues have increased from \$278M to \$693M in 1993, and \$985M in 1994. This revenue growth is attributed to (1) B&V's agility in reacting to the shift from coal and nuclear power to combined cycle power technologies, (2) prudent expansions in international markets, and (3) implementation of the POWRTRAK information technology. While profit margins on contracts have tightened due to competitive forces, the gross margin per employee continued to rise (\$30.0K in 1992, \$30.4K in 1993 and \$34.6K in 1994).

- . Preliminary Project Estimates By managing data derived from a large number (400) of projects, B&V has been able to utilize the POWRTRAK systems to make very fast (few hours) estimates with reasonable precision (+/-3 percent) for upcoming projects.

- 1 Schedule Compaction B&V claims to have reduced design and build times from 60 months to 29 months (400 MW pulverized coal unit). Given that power plants generate income in excess of \$50K/hour, this kind of schedule compaction has significant economic benefits to utility companies and is so reflected in B&V pricing for EPC services.

- 1 Risk Management B&V claims to have the lowest liability rates in the world. This was attributed in part to very low errors/omissions insurance directly related to the datacentric, shared-access features of POWRTRAK. Similarly, the capabilities to monitor progress real-time and quickly adjust and reschedule project activities provide the means to minimize schedule

impact of major disruptions, such as defaulting vendors, strikes, accidents, or natural disasters. Similar to schedule compaction, the risk management capabilities of B&V using POWRTRAK are emphasized in the marketplace.

- Data Reusability Product model data calculation sets, drawings, production schedules, etc. are all considered to be data that can be reused on similar projects. In the limit reusability can be as high as 90-92 percent. B&V practice is to duplicate project data sets so that auditable project costs can be billed from the use of such data for a new project.
- Finding Information Through the use of POWRTRAK, B&V believes that its engineers spend only about 25 percent of their project time finding information. They believe that at other companies, about 40-65 percent of the engineering time is spent finding information. *(Based a similar study, Hitachi Zosen indicated that 70 percent of their shipbuilding design office efforts are spent introduction of documents, information searches, inquiries, and communications.)*
- Structural Steel Design Mr. Voeller quoted significant engineering process improvements in this area. Because the process is strongly rule-based, it has been automated such that one person can design 21,000 tons of steel for a 3-boiler fluidized bed plant in eighteen hours. This was contrasted with fourteen people and twelve weeks utilizing manual design methods. The AISC, JAAS, and British Standards rules were said to be implemented in POWRTRAK.

One of the limitations of POWRTRAK is the proprietary nature of its architecture. Competitive systems, such as Sargent& Lundy's "Plades200," utilize more open architecture and consequently more easily share information and drawings with equipment suppliers and customers using common file formats. This situation has B&V thinking about incorporating object-linking technologies like Microsoft OLE and JAVA for Internet file sharing. Currently, data exchange with vendors and customers is limited by the capabilities of .DXF and .IGS file formats.

### 14.3 OTHER FINDINGS

Currently B&V is under a 10-year contract to General Electric to develop a version of POWRTRAK for the nuclear business. B&V is also teamed with Newport News and Ingalls for the LPD-17 competition. This was explained to be an exclusive teaming arrangement in which B&V is prohibited from teaming with anyone else relative to the LPD-17 opportunity.

Shell, DuPont, and Lloyds of London have studied POWRTRAK and estimated the savings potential for their applications. These include \$100-300M./year savings in operational support (Shell), \$51 M/year (DuPont), and 35 percent of installed cost over the life of facilities (Lloyds).

#### 14.3.1 POWRNET (the virtual power company)

Black and Veatch is moving towards becoming a significant engineer, procure, and construction (EPC) integrator in the power and petrochemical areas. Consequently, they need effective project communication across organizational boundaries. This need is leading to the creation of a virtual company involving “Partners of Choice” in global consortiums. The POWRNET effort is expected to provide capabilities for effective project team communications in a real time environment. These capabilities are viewed as essential for the close coordination and control necessary for success.

Another significant feature of the POWRNET initiative is the streamlining of specifications. Partners will resolve terms and conditions by company agreement rather than by project. Voeller spoke of reducing 200-page boiler specifications requiring fifteen days to negotiate to twenty pages negotiated in less than a day.

#### 14.3.2 Corporate Utilization

Mr. Voeller indicated that the entire Energy Group within B&V now utilizes the POWRTRAK system. This includes the Pritchard Corporation subsidiary, which involved a couple of years of convincing. The turning point came from a benchmark on a 24” stainless steel pipe within a sulphur recovery unit. The design was developed by both methods; POWRTRAK, and Pritchard’s conventional methods and systems. Three problems were not detected and/or resolved by the conventional approach, an interference, a missing foundation, and a missed opportunity to minimize required space.

### 14.3.3 Advanced Measurement Systems

Over the last several years, B&V has evaluated commercially available systems for assimilation of dimensional data in large scale (100s of feet) environments. They have concluded that existing systems are quite limited and are developing a “Ladar” (Laser-Radar) system, which is intended to improve upon currently available systems.

## **15.0 OTHER VISITS/CONTACTS**

### **15.1 INDUSTRIAL TECHNOLOGY INSTITUTE**

The expertise that the Industrial Technology Institute (ITI) will bring to the team includes:

- l Socio-technical perspectives on reengineering design and manufacturing processes so that computer modeling can be applied to good advantage.
- c Implementing large scale, electronic commerce-based, supply-chain integration in the automotive industry.
- l Developing casual models and metrics to assess the business impact of electronic commerce and computer modeling methodologies.
- “ Assessing the consequences of likely interactions between trends in information technology and business developments in manufacturing.
- l Research on the implementation of information technologies in complex organizational settings.

The ITT is actively involved in agent-based (active software objects with varying degrees of intelligence) technology development and is pursuing agent-based design support and agent-based manufacturing scheduling applications.

ITI has developed the Responsible Agents for Product-Process Interactive Design (RAPPID) project area part of the ARPA Manufacturing Automation and Design Engineering (MADE) program. It is researching the use of a community of agents that help human designers manage product characteristics across the design life cycle. Agents represent not only the designers and their tools but also components of the design itself. These agents trade with one another for design constraints, requirements, and manufacturing alternatives. The resulting marketplace provides a self-organizing dynamic that yields more rational designs faster than conventional techniques. These techniques can be applied to the design process in the shipbuilding industry. The team is involved in programs to extend the RAPPID technology to support shipbuilding design activities.

**ITI** has also developed the Autonomous Agents for Rock Island Arsenal (AARIA) application, which is part of the ARPA Agile Manufacturing Program. The intent of this project is to develop an agent-based method of factory (job shop) scheduling and control. Agent-based methods have advantages over conventional centralized approaches. They more easily adapt to changing situations, they are more robust in the event of failures, and the difficulty of integrating diverse factory elements is reduced. AARIA is using a dual approach to the problem. Both the manufacturing resources (the processing and material

handling equipment) and the material are modeled as agents that cooperate in controlling the plant floor. These agents negotiate for the allocation of resources and processing equipment to complete the necessary operations.

AARIA is implementing and testing these methods on a simulated factory and a portion of the manufacturing facility at Rock Island Arsenal. The project demonstrates the effectiveness of agent-based methods for factory control tasks in a shop floor environment. Initial research indicates that significant improvements can be made using agent-based scheduling techniques. These techniques can be adapted from the shop floor environment at Rock Island Arsenal to the production environment in the shipyard. ITI is involved in applying AARIA scheduling strategies to the manufacturing operations of the shipbuilding industry.

## 15.2 COMPUTERVISION

A short meeting was arranged with Computervision (CV) application development architects in its La Jolla, CA offices as part of the Ship Production Symposium in February 1996. The meeting allowed ComputerVision to discuss its publicly announced product development direction as it might apply to applications for the shipbuilding industry. The discussion was in the context of what CV thought was important for customers in the industry. CV has current customers in shipbuilding worldwide. Many of these customers are moving forward to build new applications around CV future product technology.

CV developers stressed the importance of scale-ability of the applications from complex to simple in terms of both product and process. Interoperable applications are a must in the future. The applications cannot tolerate data being changed and the architecture must consider required definition, appropriate tools for design, and data management. Part of the architecture must capture design intent in addition to the product or process design itself. The total system has to consider the implications of standards and the ability to incorporate “best-in-class” components into the total system.

The discussions included a description of the levels of applications with core standards at the lower levels and special purpose design and process applications at the top. Applications are expected to include context specific representations of geometry, symbology, etc. CV expects to concentrate on applications for mechanical design, die design, NC, modeling, and drafting all supported by an engine layer that deals with industry specific context issues. For example, the applications for shipbuilding would have different GUI and visualization than those same applications for AEC.

CV was very aware of the standards being contested in the marketplace. The competition between OLE/COM and CORBA will directly affect their market and they are watching the development of JAVA very closely to determine the impact of web

technology on marketing and distribution/payment approaches for CAD/CAM products in the future.

### 15.3 OTHER FINDINGS

Informal telephone conversations were conducted with several other CAD/CAM developers to assist in the technical understanding of the CAD/CAM marketplace and the potential impact on shipbuilding development in CAD/CAM/CIM.

Structural Dynamics Research Corporation (SDRC) was contacted and questions were asked of the chief development scientist. His view of factors affecting CAD/CAM/CIM were strongly influenced by SDRC'S market position in engineering analysis for structural and dynamic effects and the modeling needed to support those applications. SDRC is also moving toward a larger market share in general mechanical design based on the strength of their analysis products.

SDRC believes that UNIX workstations are still a major requirement for computer intensive modeling, viewing, and analysis. They are heavily invested in this technology and also believe that the CORBA standards are much more appropriate to their market than OLE/COM. Like CV, SDRC sees that design intent will become a major issue in effective completion of the product model. Additionally, SDRC has a significant product development effort in product data management and the supporting standards in this technology area.

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